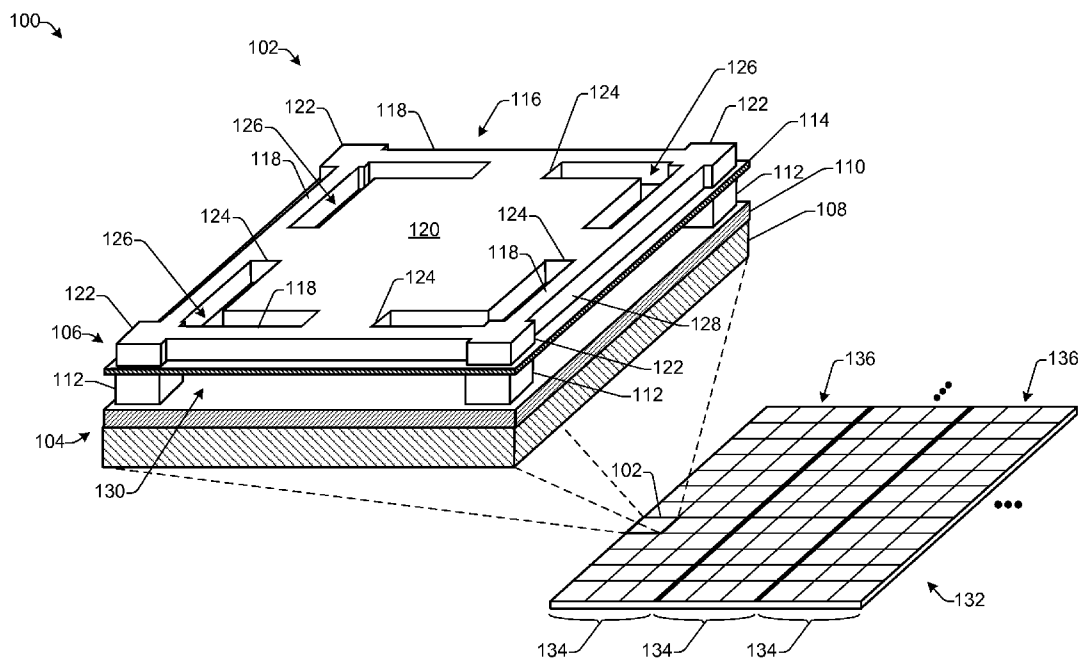




US 20160023244A1

(19) **United States**(12) **Patent Application Publication**
Zhuang et al.(10) **Pub. No.: US 2016/0023244 A1**(43) **Pub. Date: Jan. 28, 2016**(54) **HIGH DISPLACEMENT ULTRASONIC
TRANSDUCER**(52) **U.S. CL.**CPC *B06B 1/0292* (2013.01); *H02N 1/006*
(2013.01); *H04R 31/00* (2013.01)(71) Applicant: **Kolo Medical Ltd.**, Grand Cayman, KY
(US)(72) Inventors: **Xuefeng Zhuang**, San Jose, CA (US);
Yongli Huang, San Jose, CA (US); **Dave
Hong**, Los Altos, CA (US); **Lei Chen**,
Santa Clara, CA (US)(21) Appl. No.: **14/444,187**(22) Filed: **Jul. 28, 2014****Publication Classification**(51) **Int. Cl.***B06B 1/02* (2006.01)*H04R 31/00* (2006.01)*H02N 1/00* (2006.01)(57) **ABSTRACT**

In some examples, a transducer apparatus includes a spring structure that enables a large, reliable amount of displacement of a transducer plate. For instance, an individual cell of the transducer apparatus may include a substrate having a first electrode portion, with at least one spring anchor extending from a first side of the substrate. At least one spring member may be supported by the at least one anchor, and may be connected to a plate that includes a second electrode portion. Accordingly, the spring member may support the plate, at least in part, for enabling the plate to move in a resilient manner toward and away from the substrate. In some cases, the spring member may be a bar-shaped spring that is cantilevered to an anchor or supported by two or more anchors. Additionally, a cavity between the plate and the substrate may be sealed by a sealing material.



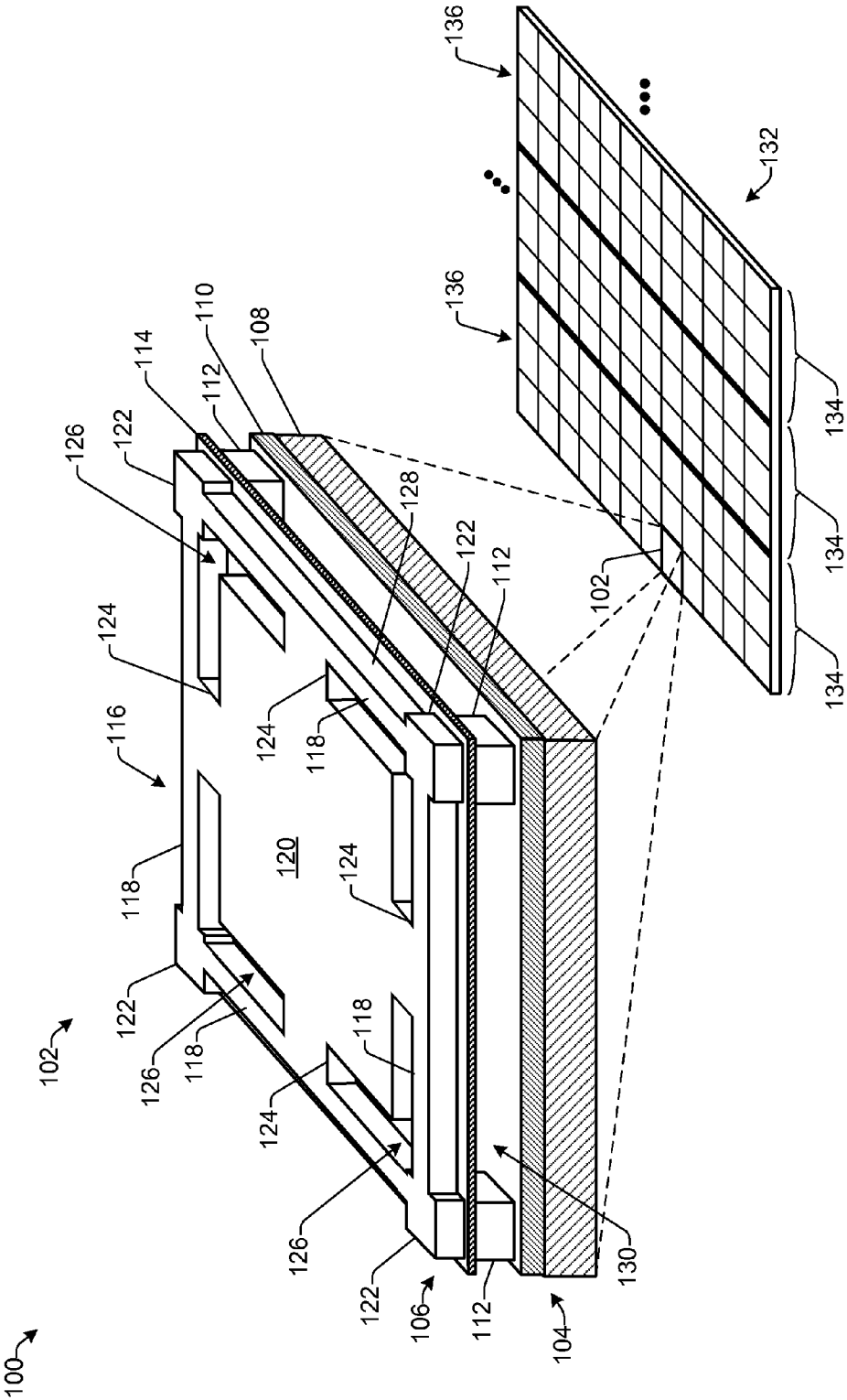


FIG. 1

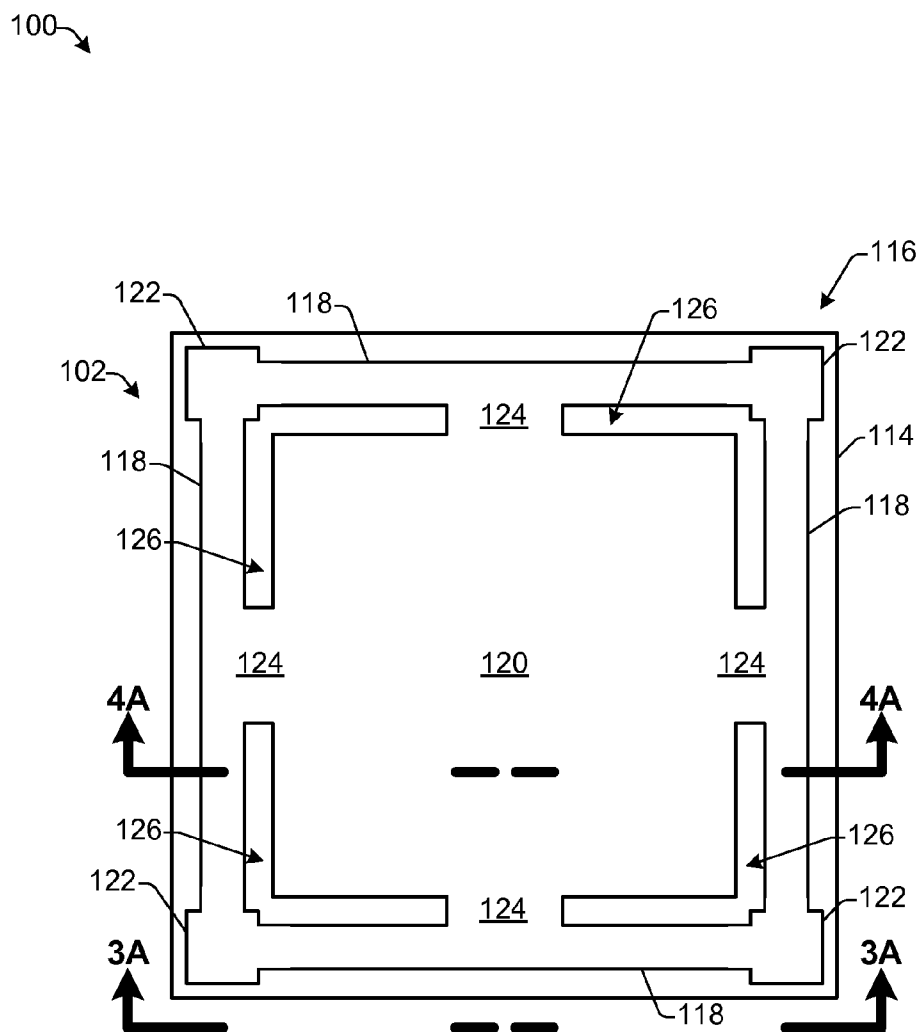


FIG. 2

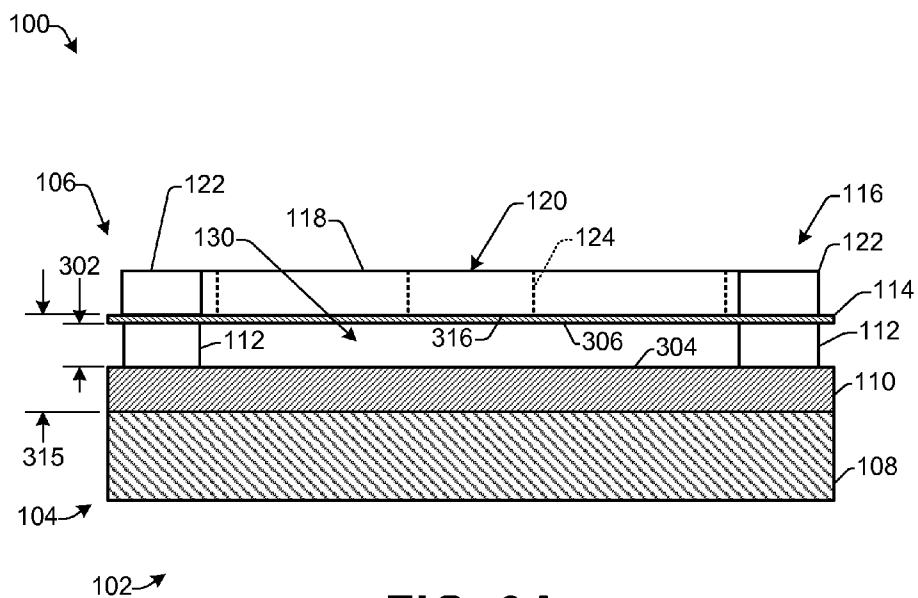


FIG. 3A

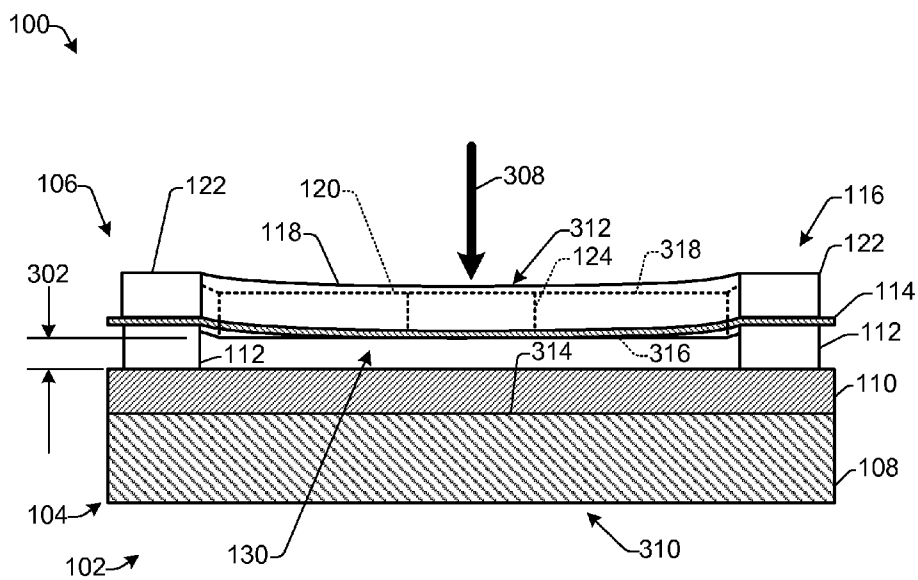


FIG. 3B

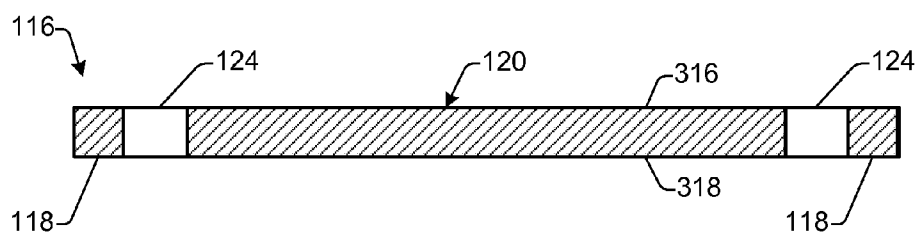


FIG. 4A

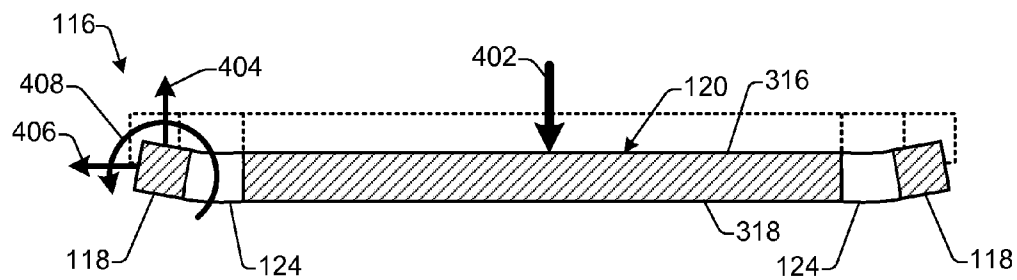


FIG. 4B

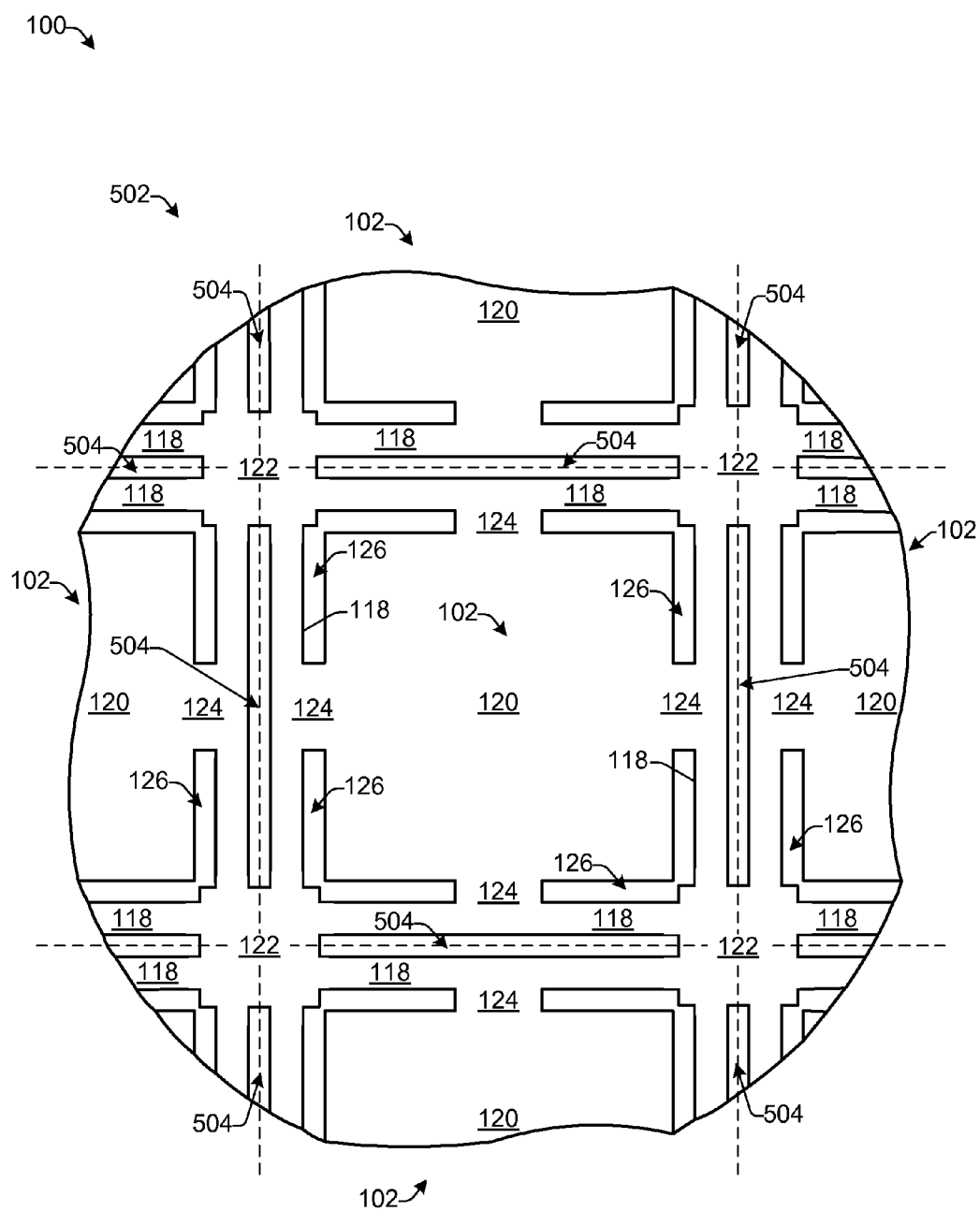


FIG. 5

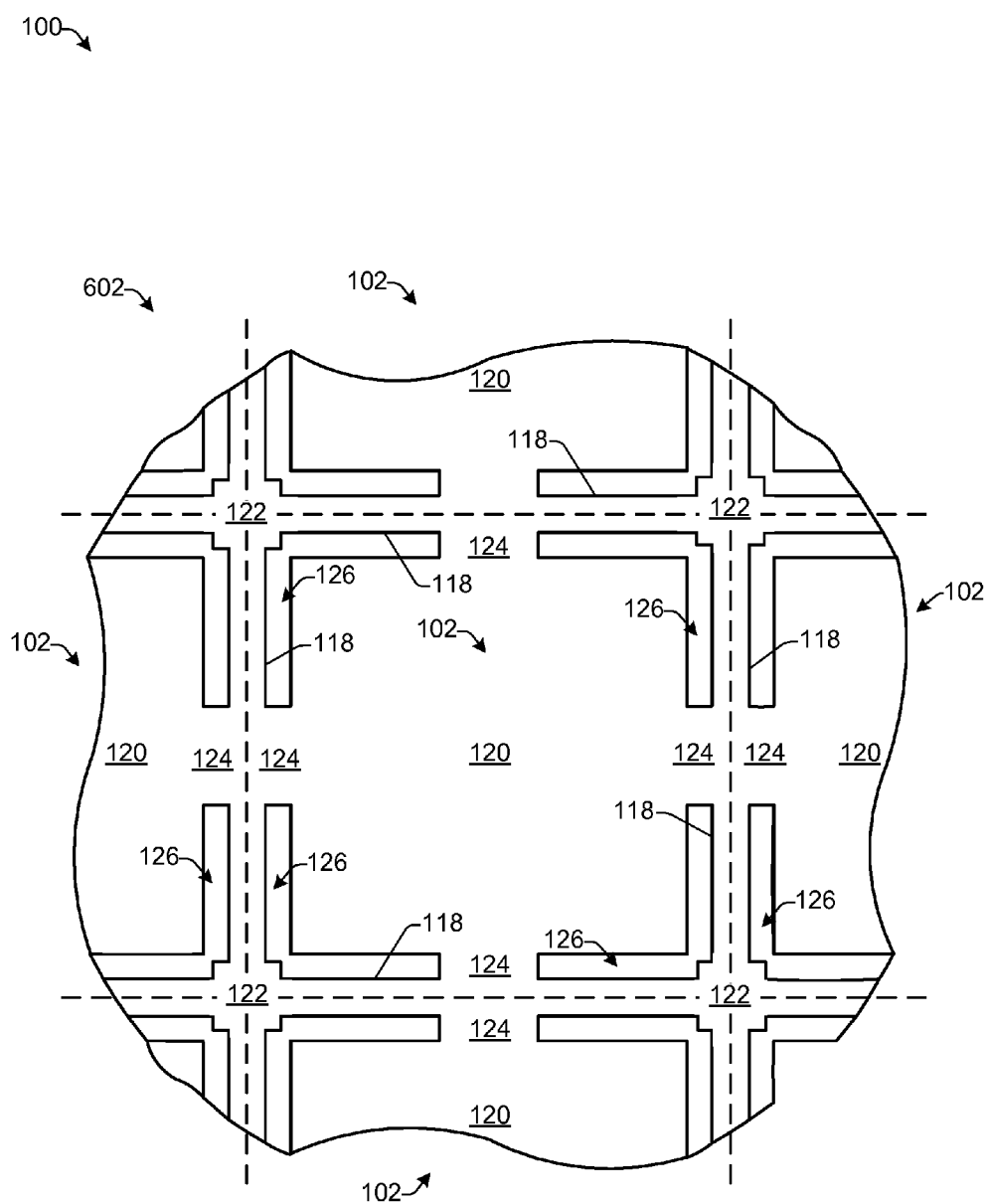
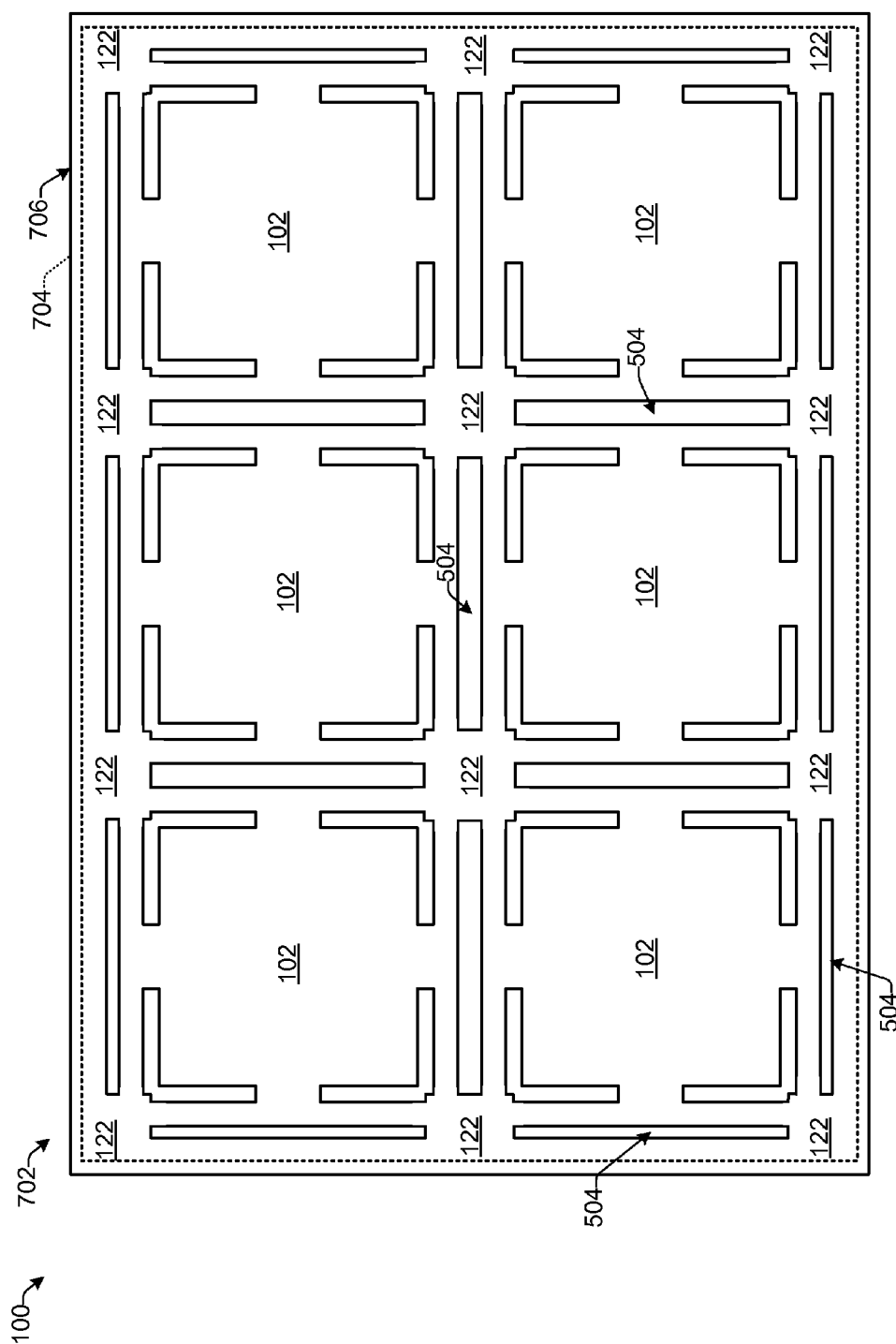


FIG. 6



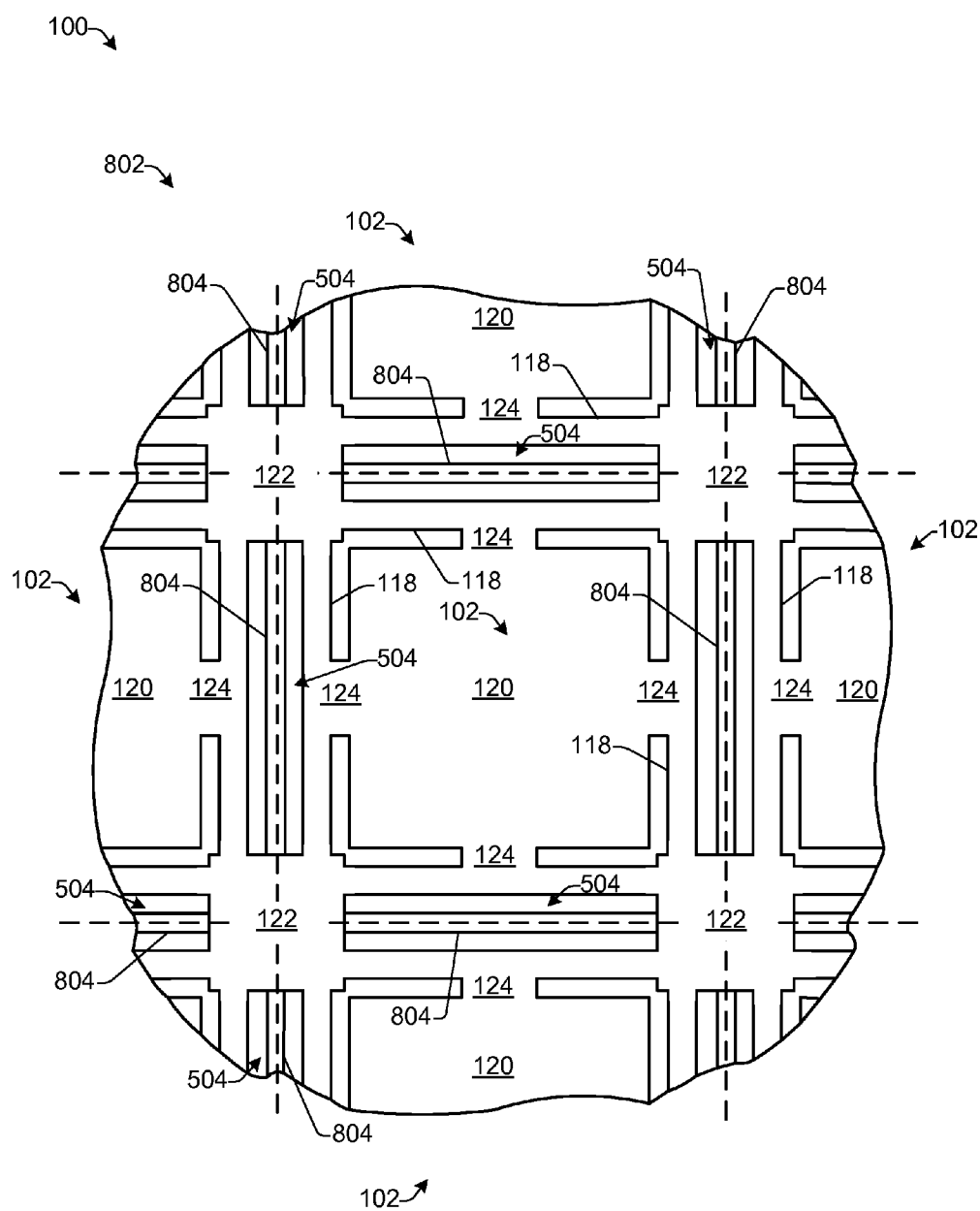


FIG. 8

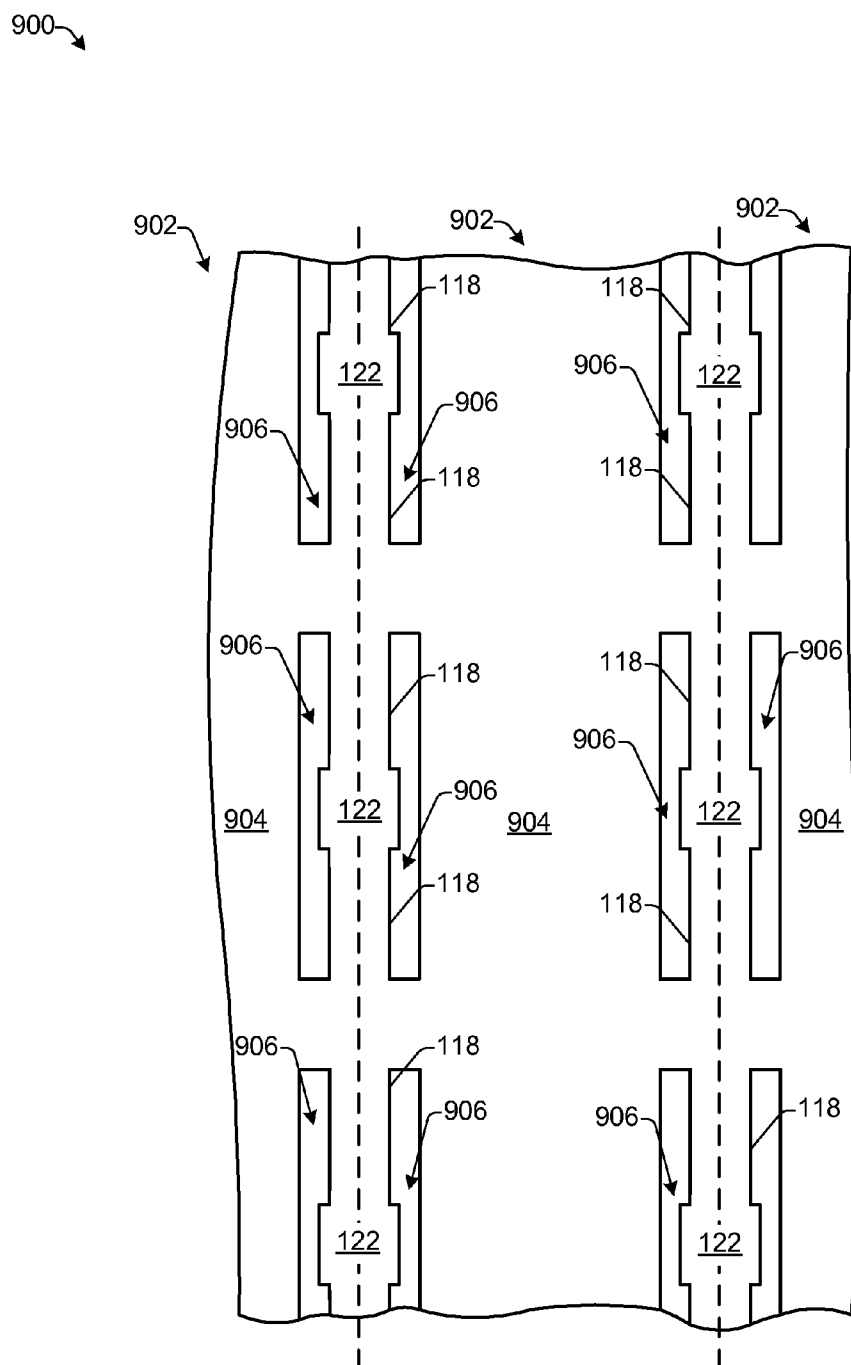


FIG. 9

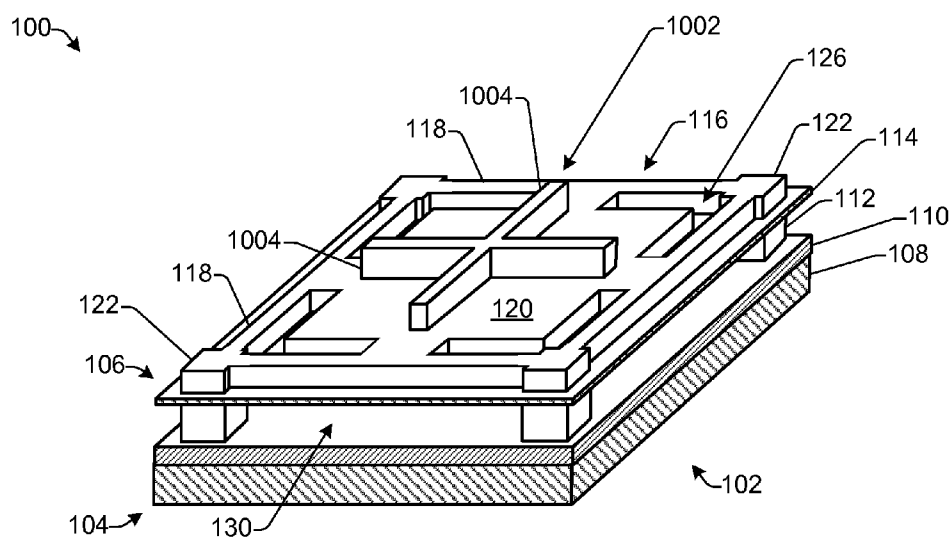


FIG. 10A

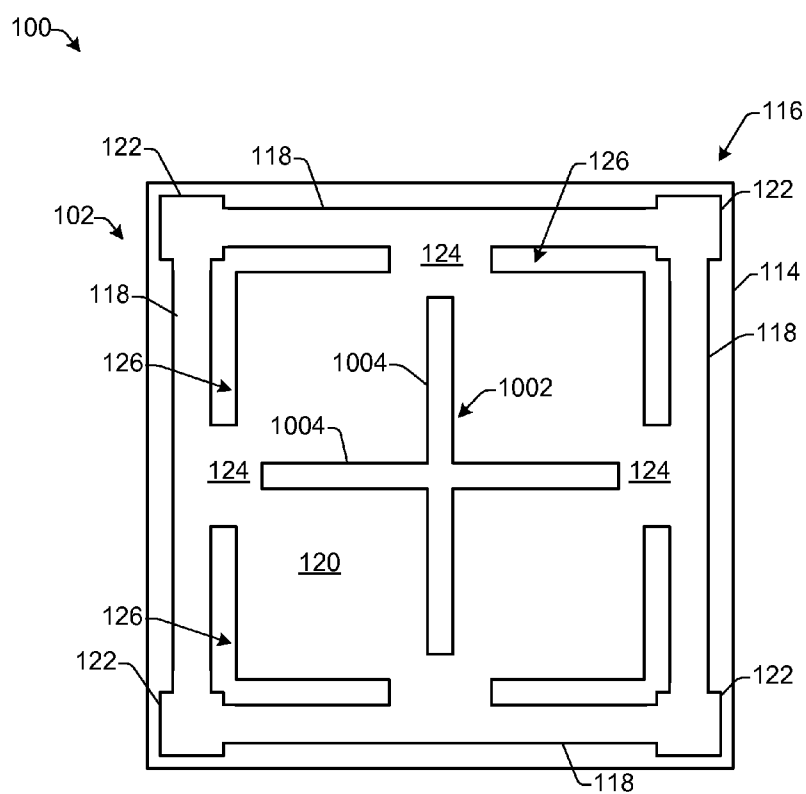


FIG. 10B

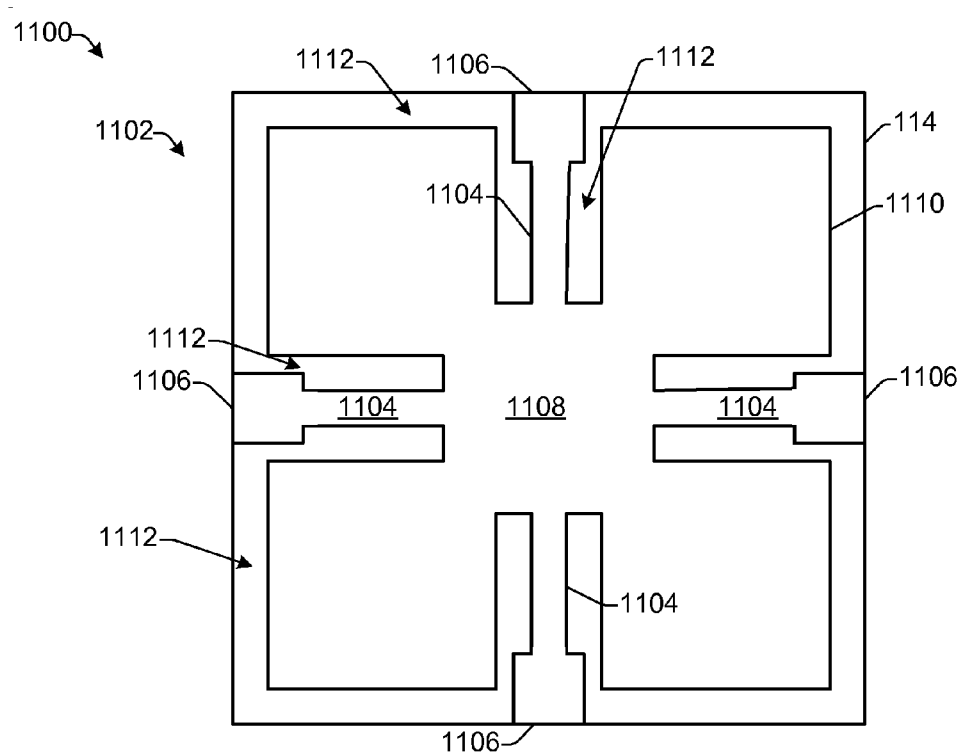


FIG. 11A

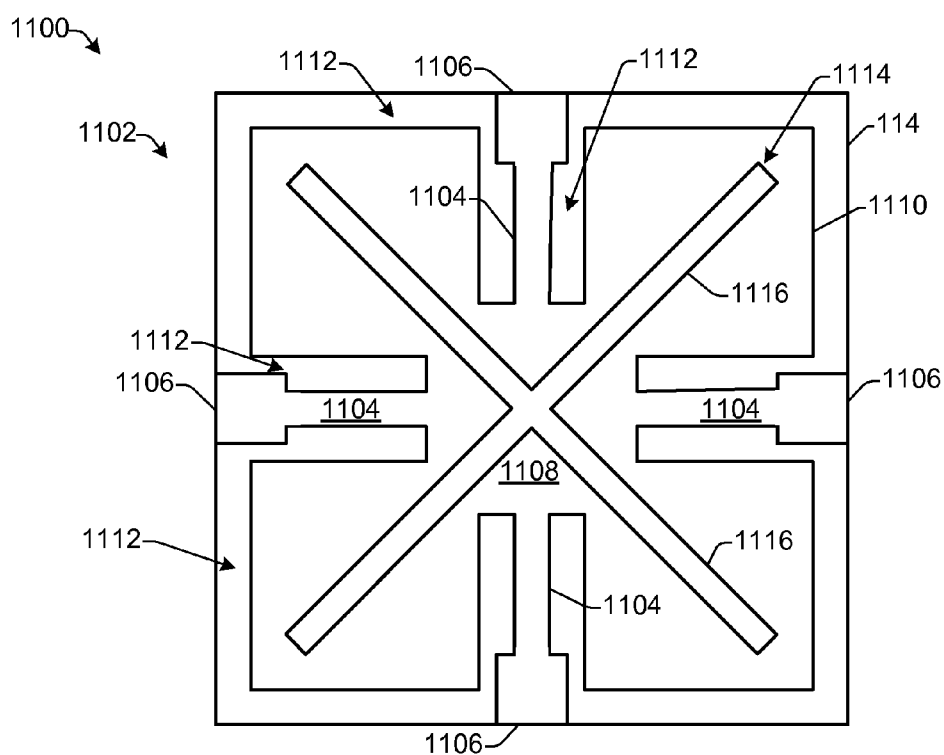


FIG. 11B

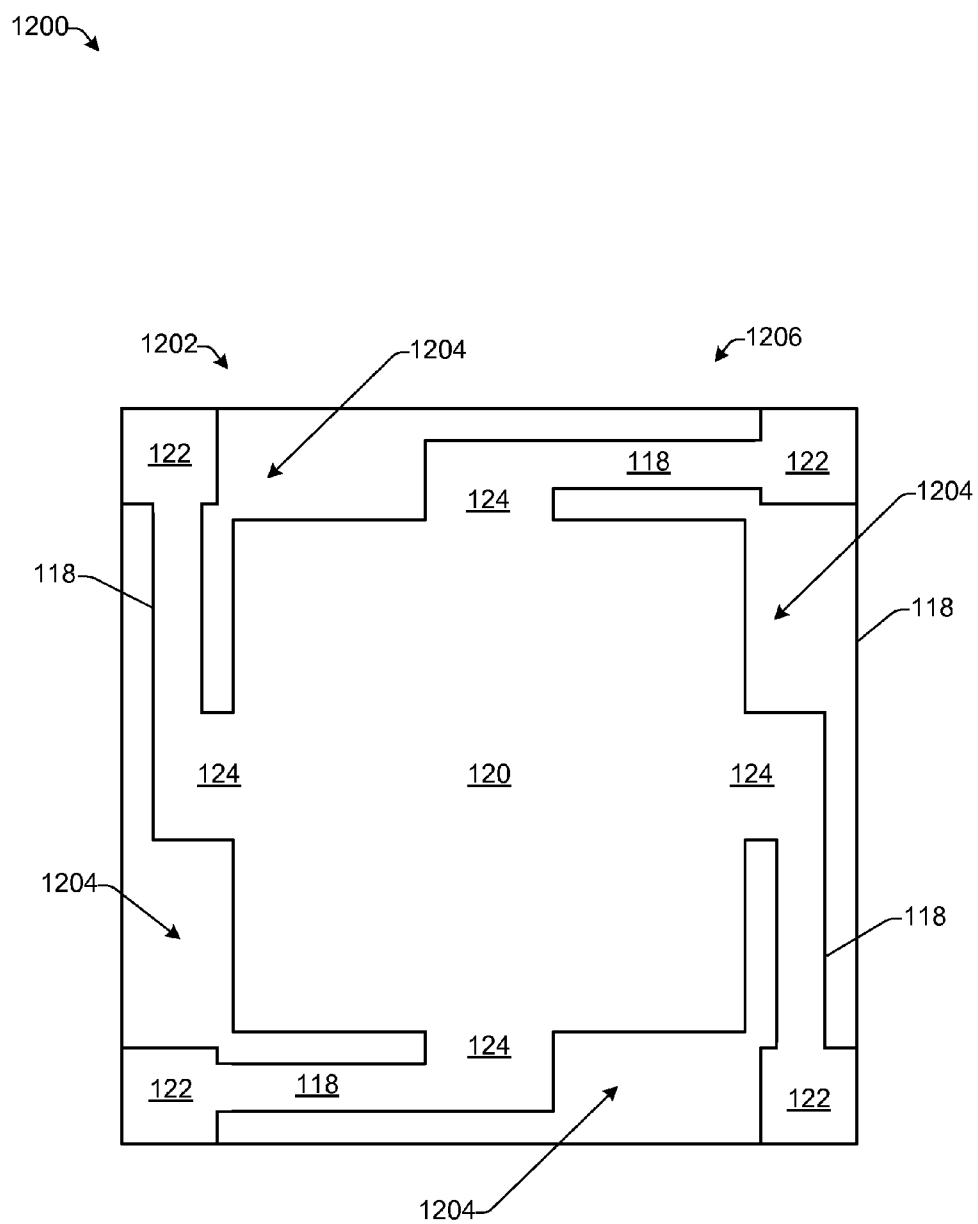


FIG. 12

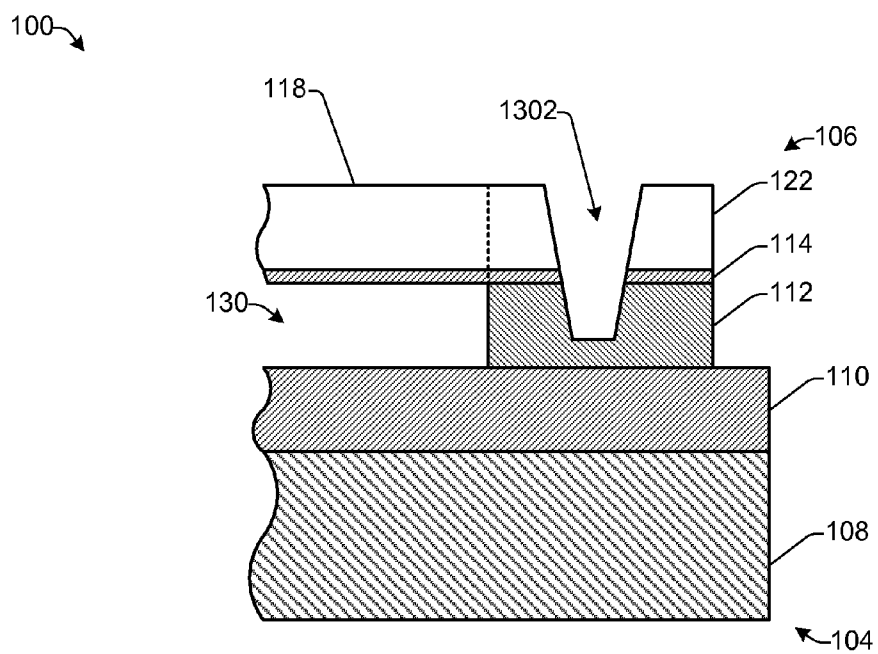


FIG. 13A

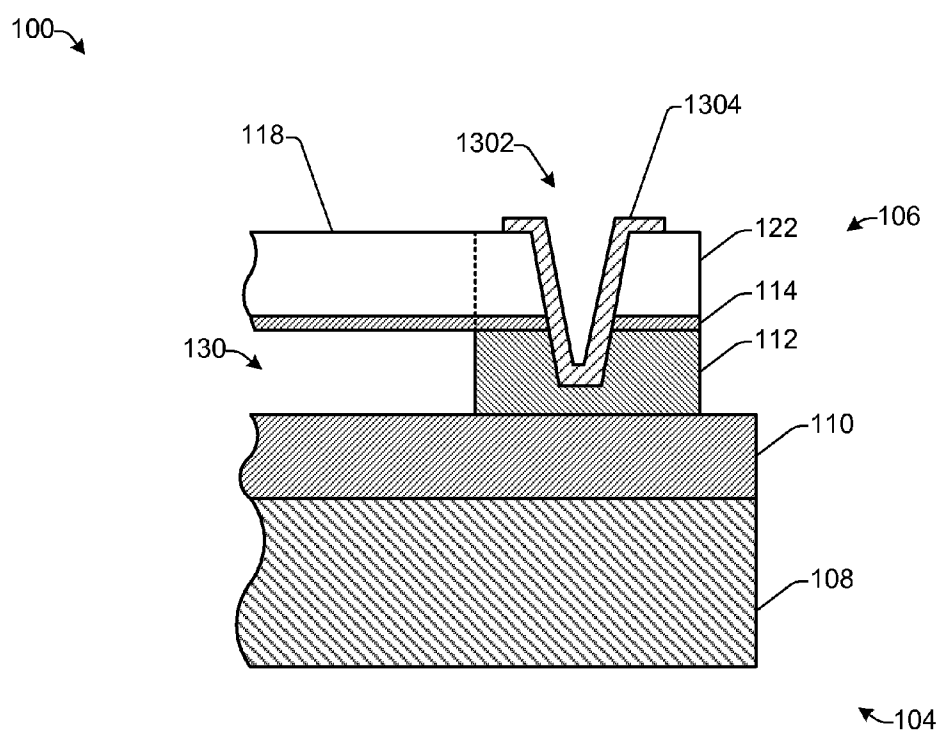


FIG. 13B

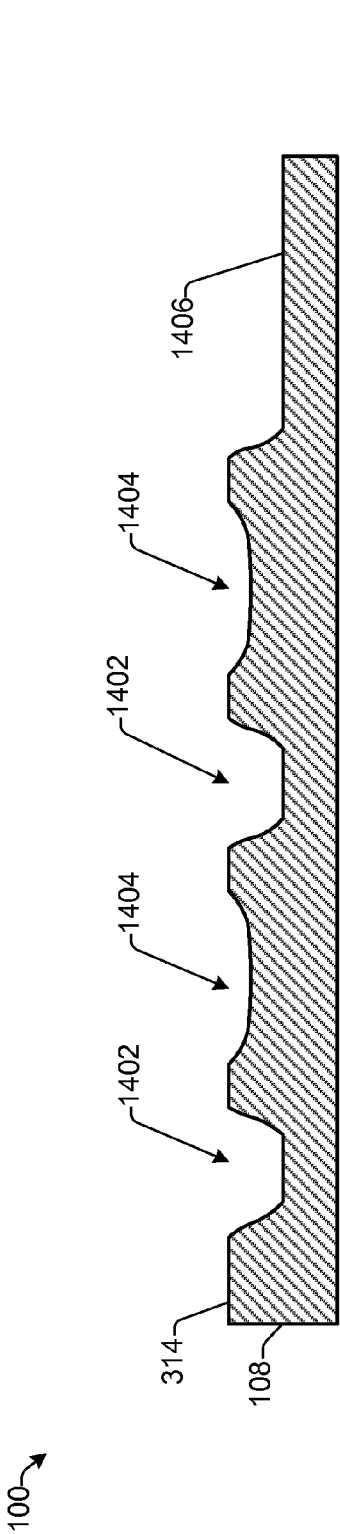


FIG. 14A

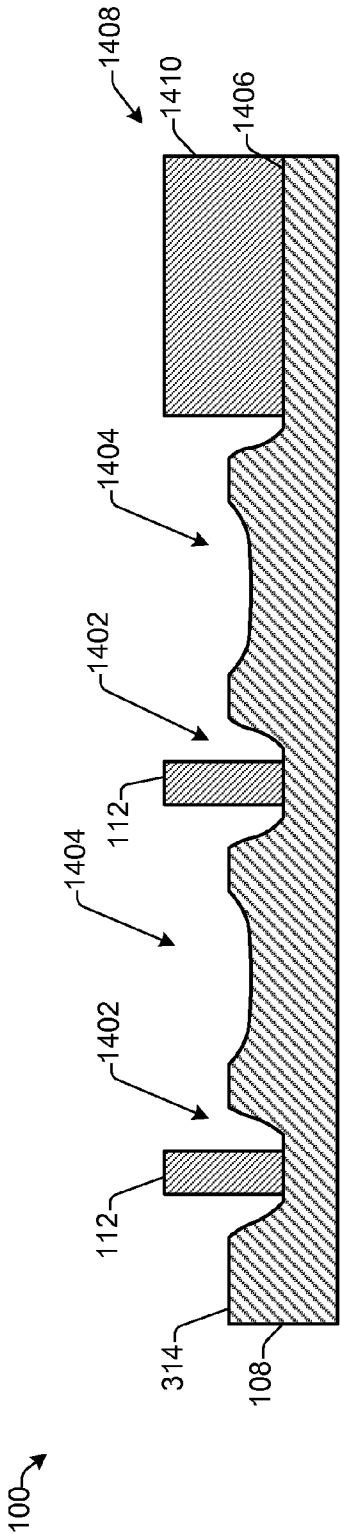


FIG. 14B

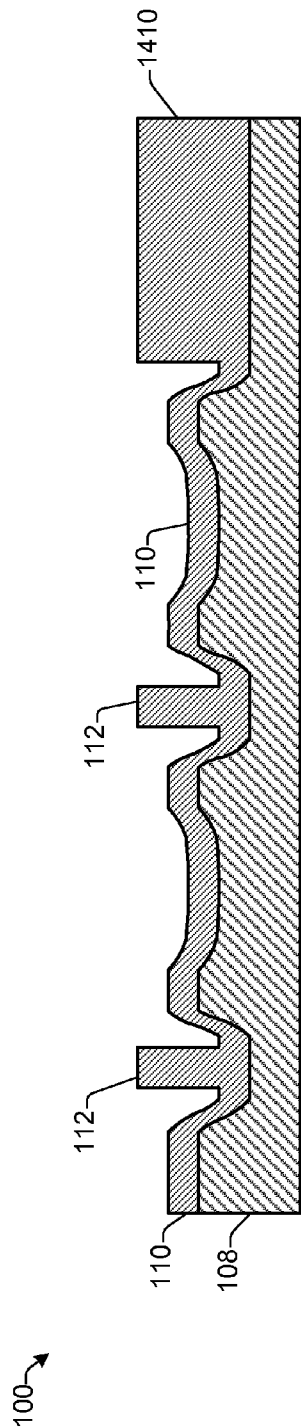


FIG. 14C

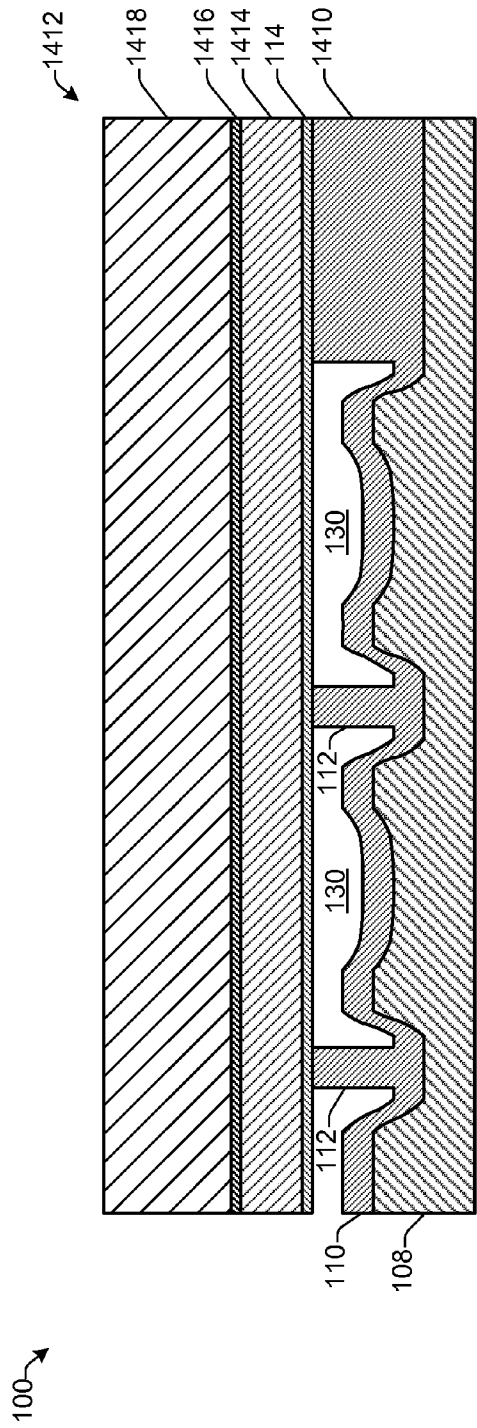


FIG. 14D

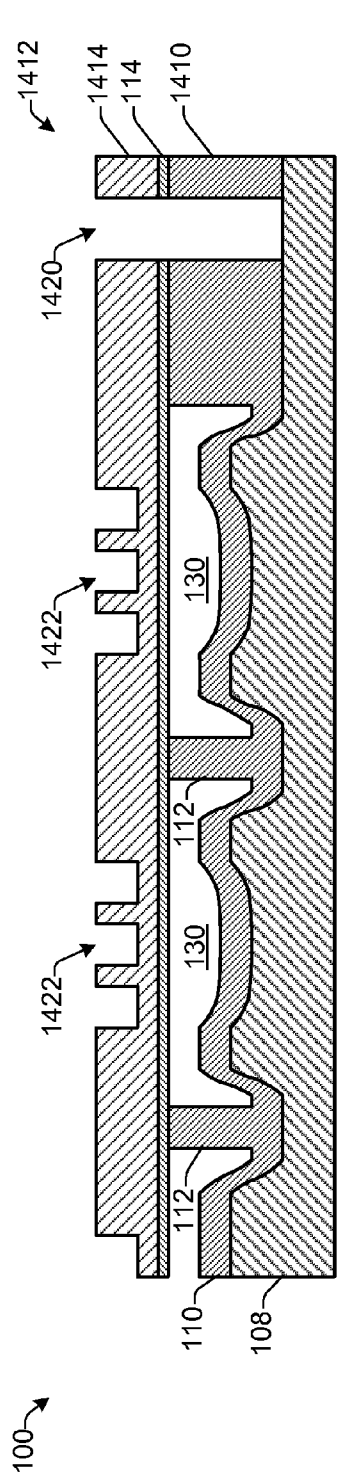


FIG. 14E

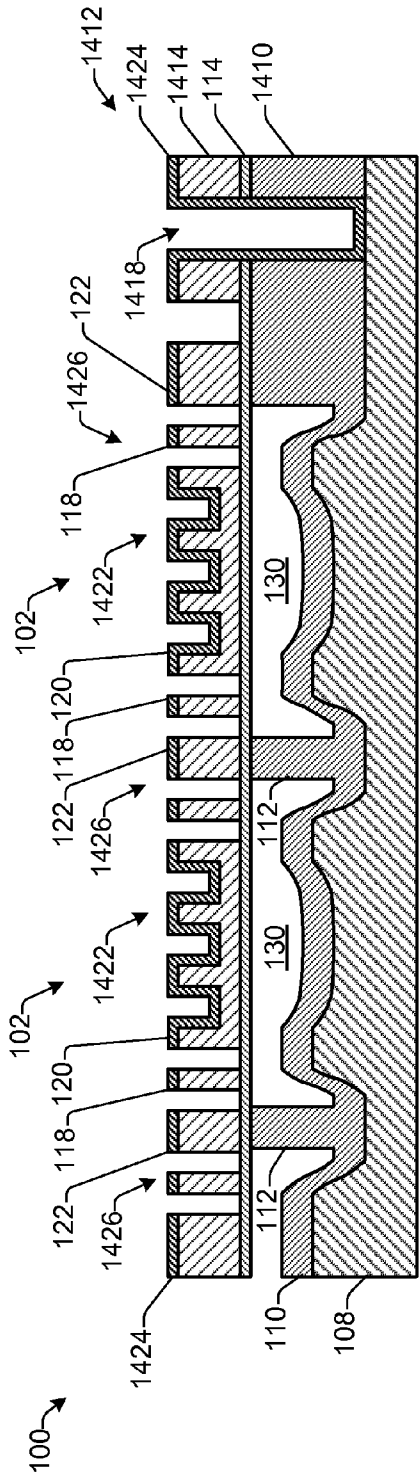


FIG. 14F

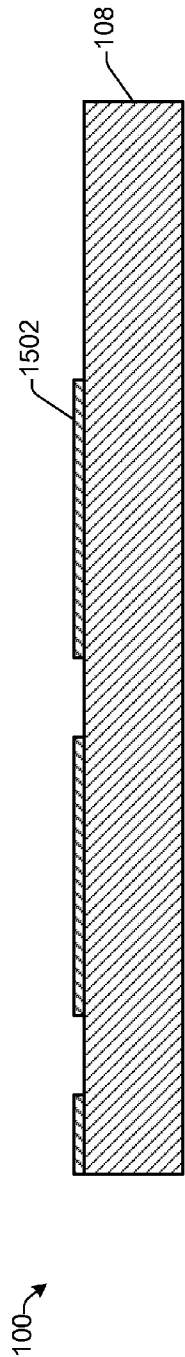


FIG. 15A

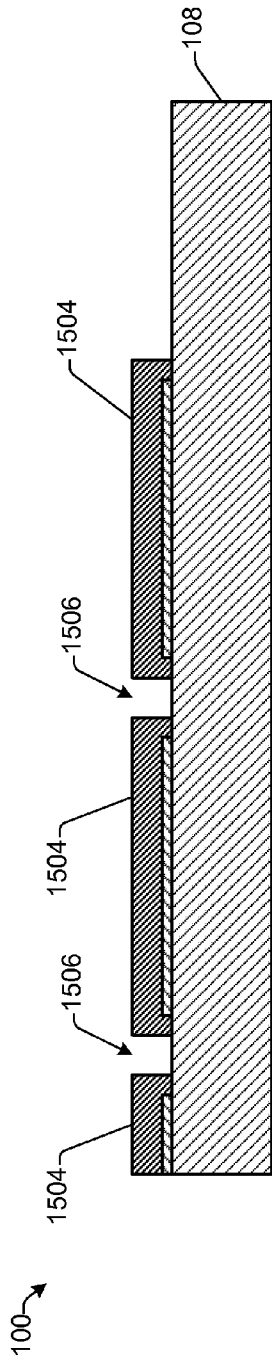


FIG. 15B

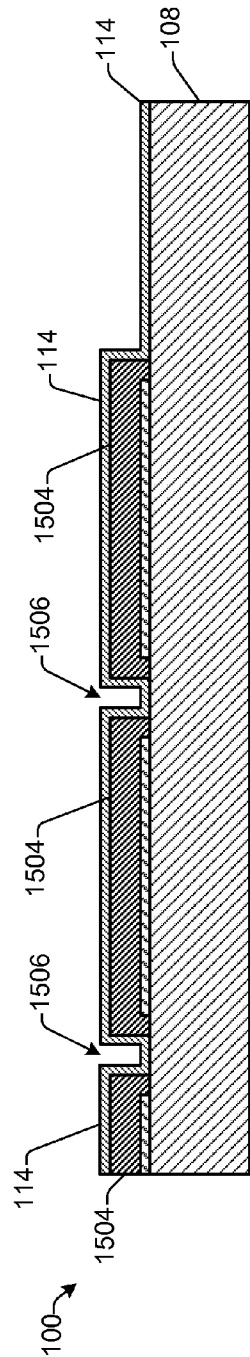


FIG. 15C

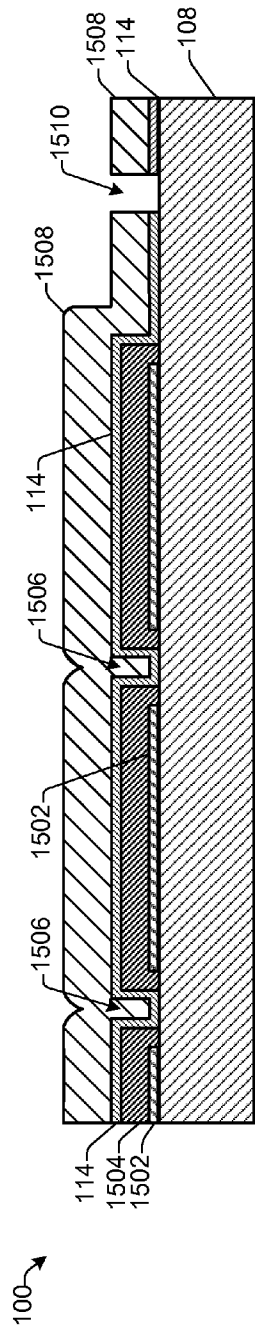


FIG. 15D

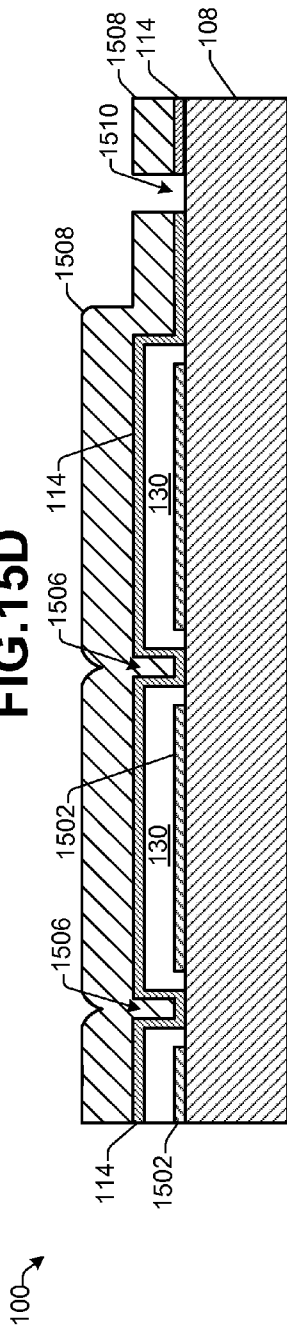


FIG. 15E

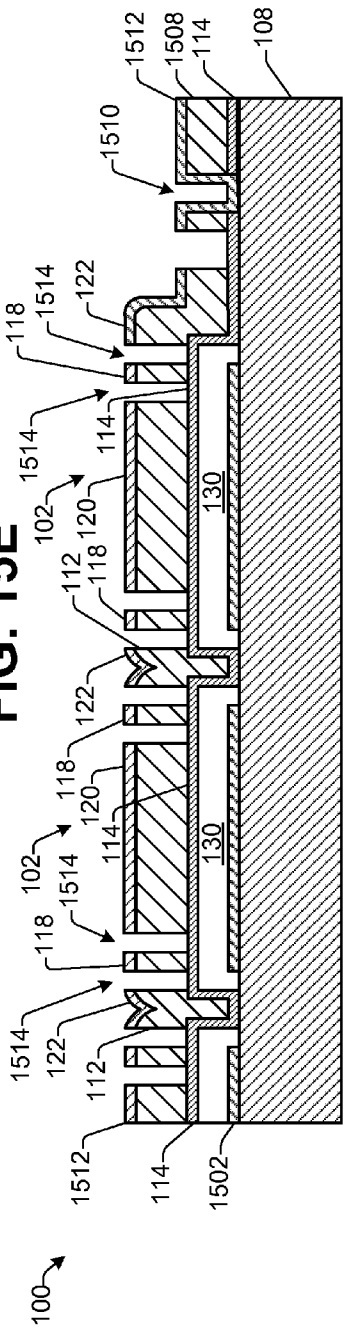
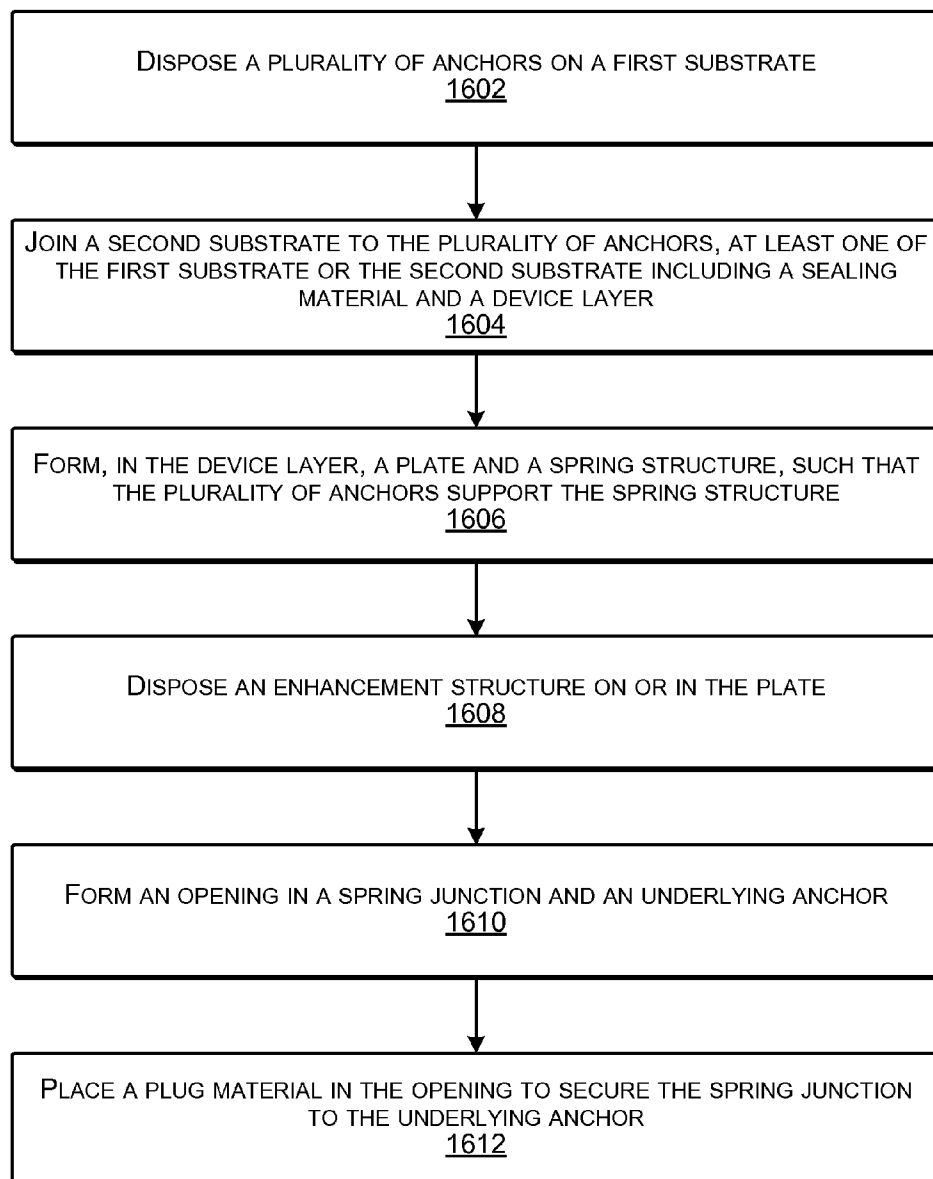
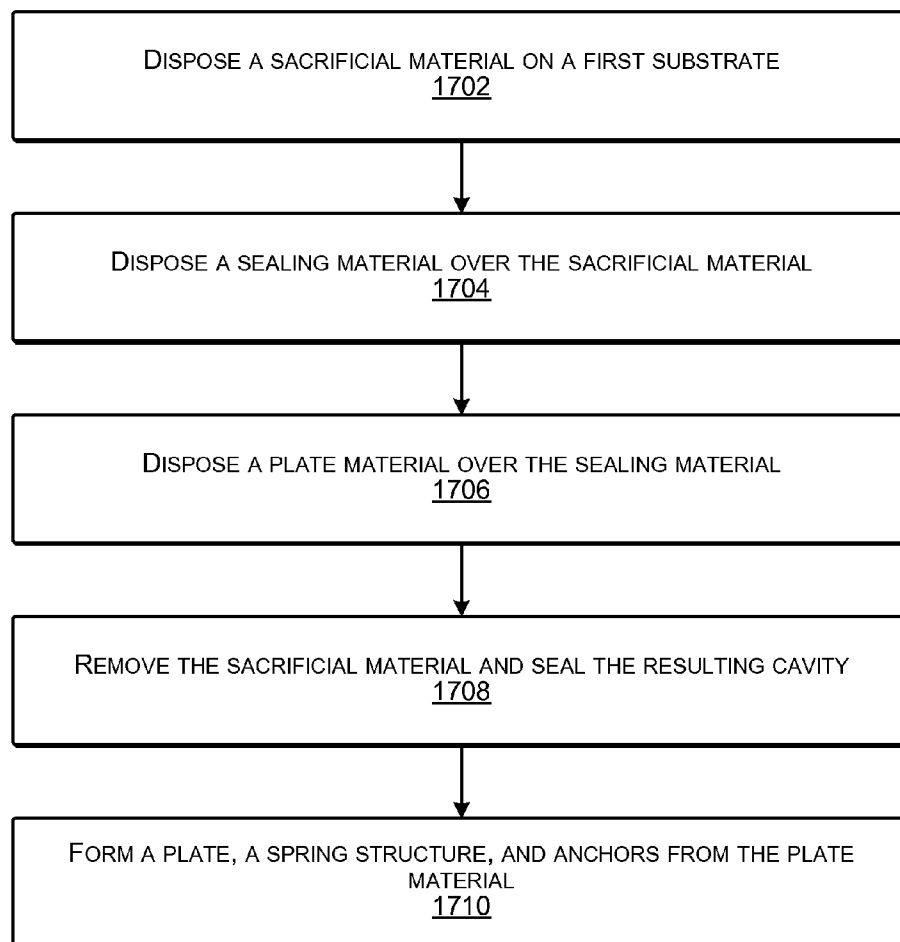


FIG. 15F

1600

**FIG. 16**

1700

**FIG. 17**

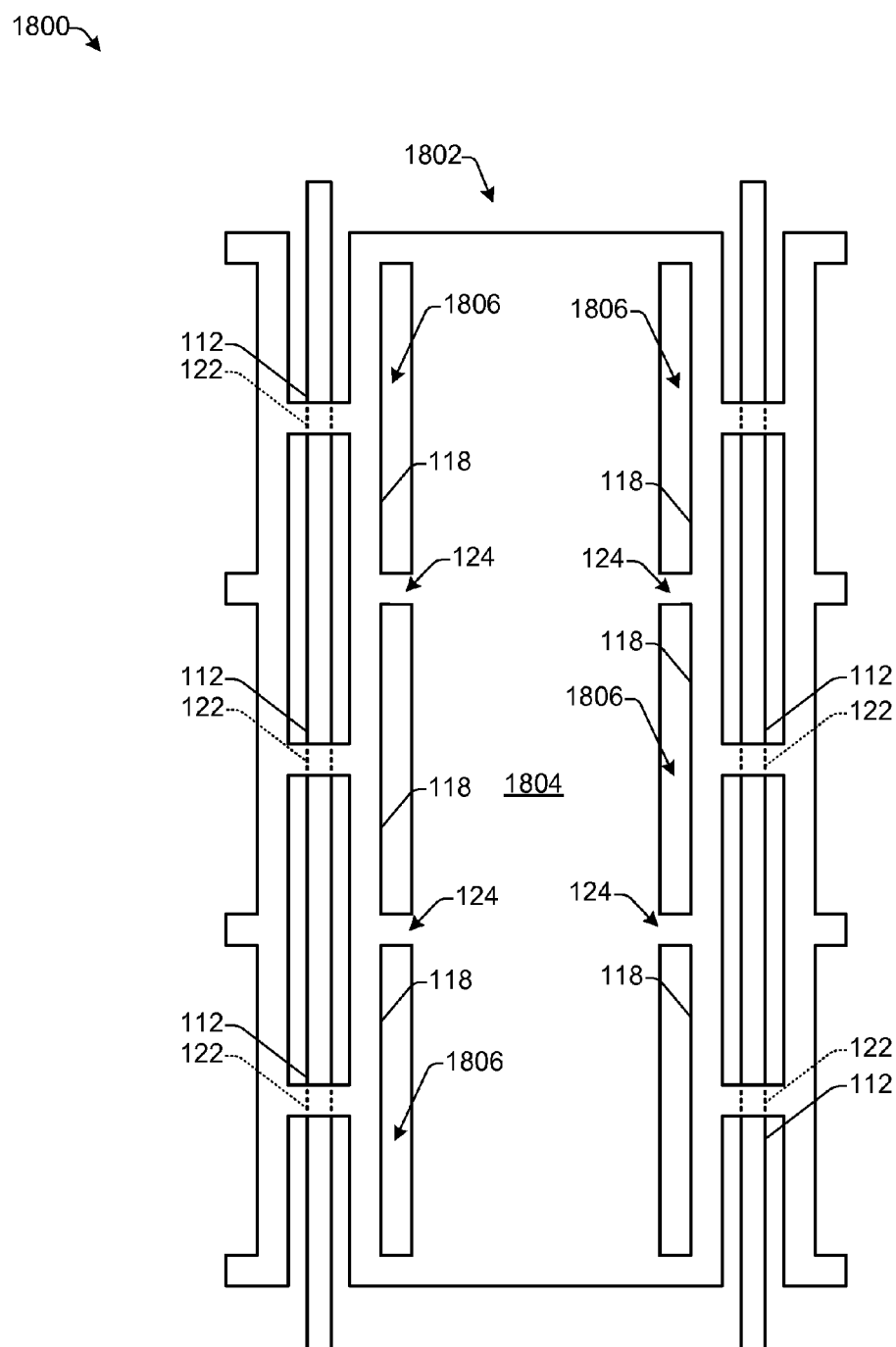


FIG.18

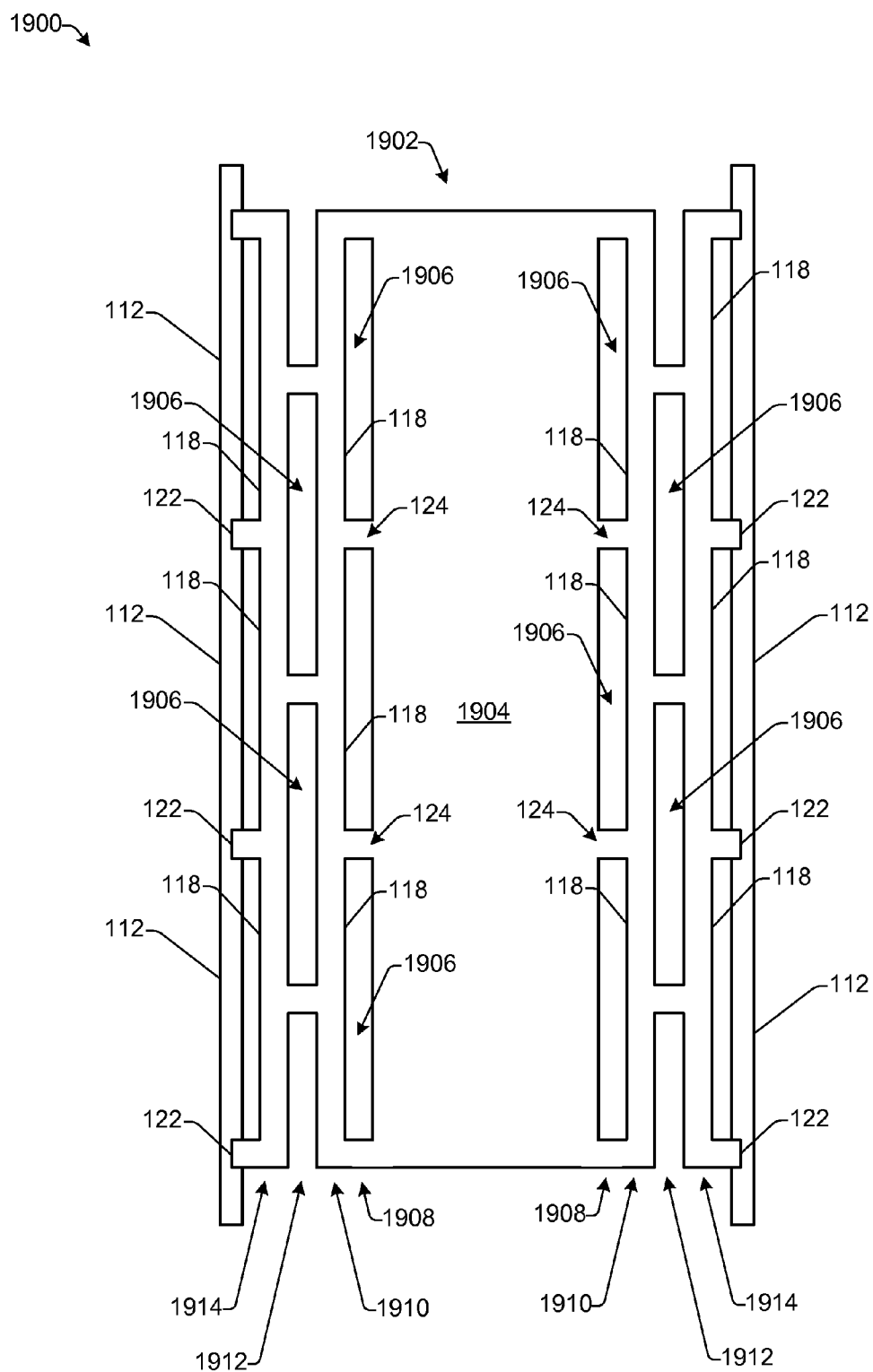


FIG.19

HIGH DISPLACEMENT ULTRASONIC TRANSDUCER

TECHNICAL FIELD

[0001] This disclosure relates to the technical field of ultrasonic transducers and transducer arrays, such as capacitive micromachined ultrasonic transducers (CMUTs) and CMUT arrays.

BACKGROUND ART

[0002] Electrostatic actuators and ultrasonic transducers may be used for various applications in a variety of media including liquids, solids and gas. For instance, ultrasonic transducers are commonly used in the medical field, such as for imaging, diagnostics, and therapy. Other uses may include biochemical imaging, non-destructive evaluation of materials, sonar, communications, proximity sensing, gas flow measurements, in-situ process monitoring, acoustic microscopy, underwater sensing and imaging, and numerous other practical applications.

[0003] An ultrasonic transducer having an electrostatic mechanism may be referred to as a capacitive ultrasonic transducer. A capacitive ultrasonic transducer fabricated using micromachining techniques may be referred to as a capacitive micromachined ultrasonic transducer (CMUT). A typical CMUT may include at least two electrodes and a transducing space (e.g., a separation gap) between the two electrodes that allows one of the electrodes to be physically displaced toward and away from the other electrode during operation. For example, some CMUTs may include a flexible membrane that allows displacement of one or more of the electrodes. However, the displacement capability of such membranes may be limited due to various factors, such as the materials used, the physical configurations of the membranes and the CMUTs in which they are employed, and so forth.

BRIEF DESCRIPTION OF THE DRAWINGS

[0004] The detailed description is set forth with reference to the accompanying figures. In the figures, the left-most digit(s) of a reference number identifies the figure in which the reference number first appears. The use of the same reference numbers in different figures indicates similar or identical items or features.

[0005] FIG. 1 illustrates a perspective view of an example of a cell of a transducer apparatus according to some implementations.

[0006] FIG. 2 illustrates a topside plan view of the example transducer cell of FIG. 1 according to some implementations.

[0007] FIGS. 3A and 3B illustrate a side view of the example cell of FIG. 1, as taken along line 3A-3A of FIG. 2 according to some implementations.

[0008] FIGS. 4A and 4B illustrate a cross-sectional view of a portion of the example cell of FIG. 1, as taken along line 4A-4A of FIG. 2 according to some implementations.

[0009] FIG. 5 illustrates an example transducer apparatus including a plurality of the example transducer cells arranged in at least a portion of an array according to some implementations.

[0010] FIG. 6 illustrates an example transducer apparatus including a plurality of the example transducer cells arranged in at least a portion of an array according to some implementations.

[0011] FIG. 7 illustrates an example transducer apparatus including a plurality of the example transducer cells arranged in at least a portion of an array according to some implementations.

[0012] FIG. 8 illustrates an example transducer apparatus including a plurality of the example transducer cells arranged in at least a portion of an array according to some implementations.

[0013] FIG. 9 illustrates an example transducer apparatus including a plurality of example transducer cells arranged in at least a portion of an array according to some implementations.

[0014] FIGS. 10A and 10B illustrate a perspective view and a plan view, respectively, of an example cell of a transducer apparatus including a plate enhancement element according to some implementations.

[0015] FIGS. 11A and 11B illustrate plan views of example cells of a transducer apparatus according to some implementations.

[0016] FIG. 12 illustrates a plan view of an example cell of a transducer apparatus according to some implementations.

[0017] FIGS. 13A and 13B illustrate a cross-sectional view of an example anchor of a transducer apparatus according to some implementations.

[0018] FIGS. 14A-14F illustrate a side cross-sectional view of a transducer apparatus during select fabrication operations according to some implementations.

[0019] FIGS. 15A-15F illustrate a side cross-sectional view of a transducer apparatus during select fabrication operations according to some implementations.

[0020] FIG. 16 is a flow diagram of an example process for fabricating a transducer apparatus according to some implementations.

[0021] FIG. 17 is a flow diagram of an example process for fabricating a transducer apparatus according to some implementations.

[0022] FIG. 18 illustrates an example transducer apparatus according to some implementations.

[0023] FIG. 19 illustrates an example transducer apparatus according to some implementations.

DESCRIPTION OF THE EMBODIMENTS

[0024] This disclosure includes techniques and arrangements for a transducer apparatus that includes a spring structure that enables a large, consistent amount of displacement of a transducer element. For example, an individual cell of the transducer apparatus may include a substrate having a first electrode portion, with at least one post or other suitable spring anchor extending from a first side of the substrate. At least one spring member may be supported by the at least one anchor, and may be connected to a plate that includes a second electrode portion. Accordingly, the spring member suspends, or otherwise supports the plate, at least in part, for enabling the plate to move in a resilient manner toward and away from the substrate.

[0025] In some implementations, the at least one spring member may be a beam spring, a leaf spring, or other type of bar-shaped spring that is supported by the at least one anchor. As one example, the spring member may be supported between a pair of anchors e.g., with one anchor supporting each end of the spring member. In other examples, the spring member may be cantilevered from a single anchor. In addition, in some instances, an individual cell of the transducer apparatus may include two, four, or more, anchors that sup-

port multiple spring members, which in turn support the plate that includes the second electrode portion. As one example, the plate may be shaped as a square or other rectangle, or any of various other shapes, such as circular, hexagonal, triangular, and so forth. In the case that the plate is a rectangle, there may be a spring member disposed on each of the four sides of the plate, such as configured in a rectangular pattern around the plate. Furthermore, in some cases, the springs and the plate may be fabricated from a single piece of material, such as by etching, deposition or other suitable micromachining techniques. Accordingly, various micromachining methods may be used to fabricate the transducer apparatus herein, such as etching (e.g., sacrificial etching, surface micromachining), wafer bonding, deposition, combinations thereof, or any other suitable fabrication techniques that are known or that may become known.

[0026] In some instances, the first electrode portion may serve as a first electrode of a capacitive micromachined ultrasonic transducer (CMUT), and the second electrode portion may serve as a second electrode of the CMUT. In addition, a transducing gap may exist between the plate and the substrate, such that a capacitance may exist between the first electrode and the second electrode. Changes in the transducing gap, e.g., changes in the distance of the plate from the substrate, may correspond to changes in the capacitance between the first electrode and the second electrode. For instance, the CMUT may be a generally parallel plate capacitor in which the second electrode is movable towards and away from the first electrode through flexing of the at least one spring member. The electrodes may be used to transmit (TX) or receive (RX) an acoustic wave in an adjacent medium. In some examples, a DC bias voltage may be applied between the electrodes to provide a baseline deflection of the plate to an optimum position for CMUT operation, typically with the goal of maximizing sensitivity and/or bandwidth.

[0027] During transmission an electrical signal, such as an AC signal, may be applied to the CMUT by an electronic circuit. The alternating electrostatic force between the first electrode and the second electrode causes the plate to move towards and away from the substrate (e.g., vibrate), and thereby deliver acoustic energy into a medium adjacent to the CMUT. During reception, incoming acoustic energy may impinge on the plate thereby moving the plate toward and away from the substrate i.e., moving the second electrode toward and away from the first electrode, thus altering the capacitance between the two electrodes. The changes in capacitance may be detected by an electronic circuit and the resulting electric signal may be analyzed or otherwise processed to determine characteristics of the incoming acoustic energy.

[0028] In some examples herein, the bottom substrate and/or the upper plate material may be conductive. For instance, if the substrate itself is conductive, then the substrate may serve as the first electrode. Similarly, if the material from which the plate is constructed is conductive, then the plate itself may serve as the second electrode. In other examples, conductive material may be patterned or otherwise deposited onto the substrate to form the first electrode. As another example, one or more select areas of the substrate may be doped to make the one or more areas conductive, while a remainder of the substrate may remain dielectric or nonconductive. Similarly, if the plate is not made of a conductive material, the second

electrode may be patterned onto the bottom or the top of the plate, the plate may be doped to make the plate conductive, and so forth.

[0029] As mentioned above, the transducer apparatus includes a transducing gap, which includes a cavity between the plate and the substrate. In some examples, the transducer apparatus further comprises a sealing layer to seal, at least in part, the cavity. For instance, the cavity may be sealed so that liquid, gas or other substance is not able to enter into the cavity, such as in the case in which transducing apparatus is submerged into a liquid. Additionally, in some examples, a vacuum may be applied within the gap, or the gap may be filled with an inert gas, such as nitrogen, and the sealing material may be non-conductive. As one example, the sealing member can be a thin film layer of sealing material positioned below or above the plate(s) and/or spring member(s). As another example, the sealing material may be placed within any openings between the spring member(s) and the plate(s). For instance, the sealing material may be relatively flexible (e.g., more flexible than the spring members and the plate), so that sealing material has minimal effect on the displacement difference between adjacent CMUT components (e.g., spring member(s), plate(s) and anchor(s)). In some examples, the sealing member may be a single layer of sealing material. In other examples, the sealing material may include multiple layers, which may be contiguous or noncontiguous with each other.

[0030] In the examples herein, the spring members may be more flexible than the plate, so that the plate has relatively larger and consistent displacement during operation of the CMUT. For instance, the spring member(s) may be substantially more flexible than the plate so that the movement of an active surface of the CMUT is primarily due to deformation of the spring structure rather than the plate. Consequently, there may be relative displacement between the spring member(s) and the plate, and sealing material may be disposed so as to seal the openings among the spring structure, the anchor(s) and the plate (i.e., openings between the spring structure and plate, between the spring structure and the anchor(s), between the anchor(s) and the plate, etc.) to help keep the cavity sealed, such as for maintaining a vacuum within the cavity.

[0031] In some implementations, the transducer apparatus may include multiple basic structure units or cells. As one example, a plurality of the cells may be fabricated together, e.g., in a side-by-side configuration, such as to form an array element of the transducer apparatus, and a plurality of the array elements may be fabricated concurrently, e.g., in a side-by-side configuration, such as to form an array of the transducer apparatus. Alternatively, in other examples, any arrangement of a plurality of cells may form an array. As mentioned above, each cell may include a substrate, one or more anchors to support the spring structure, the plate, the sealing material, two electrodes, and a cavity sealed underneath the plate to provide a transducing gap between the plate and the substrate. The cells in the CMUT can be the same as each other or different from each other. In some examples, one or more of the cells may share a spring structure or/and an anchor with one or more neighboring cells. Furthermore, in some cases, each cell may have an individually sealed cavity, or alternatively, multiple cells have connected cavities that are sealed together. Accordingly, the cavity may be sealed by the plate, the spring structure, the sealing material, the spring anchor(s) and/or the substrate.

[0032] The spring structure may connect to any suitable position on the plate. As one example, an individual spring member may connect to the plate at an edge of the plate. In addition, the spring structure may be arranged around the perimeter of the edge of the cell to maximize the average displacement of the plate within the cell. In some examples, the thickness of an individual spring member may be controlled to be approximately the same as that of the plate. As one particular example, the spring member may have an approximately square or similar rectangular cross-section. In other examples, the spring member may have a circular cross-section, a triangular cross-section, an I-beam cross-section, an L-shaped cross-section, a T-shaped cross-section, or any other suitable cross-section. Additionally, in some examples, plugs may be applied to one or more of the anchors to enhance the strength of the connection of individual spring members to the anchors. For example, the plug may be inserted into a via or other opening formed in the spring member and the anchor.

[0033] Furthermore, in some examples, the spring structure and the plate may share at least one layer of the same material. Additionally, or alternatively, in some examples, the spring structure and the plate may be fabricated from a single piece of material, such as from a single contiguous substrate. The plate of the transducer apparatus may have a uniform thickness or a variable thickness. As one example of a plate with variable thickness, the plate may include an enhancement structure, such as one or more stiffening elements, so that the plate has the improved rigidity, with less mass, than a plate of comparable mass and material having a uniform thickness. Furthermore, the plate (or the entire cell) can have any of numerous different shapes such as square, rectangular, circular, hexagonal, triangular, or any other desired shape.

[0034] Some examples herein are described in the context and environment of a CMUT for transmitting and receiving ultrasonic energy. However, implementations herein are not limited to the examples described, and may be extended to other contexts and other environments, as will be apparent to those of skill in the art having the benefit of the disclosure herein.

[0035] FIG. 1 illustrates a perspective view of an example basic structural unit of a transducer apparatus 100 according to some implementations. In some instances, the basic structural unit of the transducer apparatus may be referred to as a cell 102, and a plurality of the cells 102 may be arranged adjacent to each other to form at least a portion of an array, as described elsewhere herein. In the illustrated example, the cell 102 includes a lower structure 104 and an upper structure 106. The lower structure 104 includes a substrate 108, an optional insulation layer 110, and one or more spring anchors 112. For example, a plurality of anchors 112 may extend from the upper side of the substrate 108. In some instances, the anchors 112 may be shaped as posts, and may be made from a non-conductive material, such as an oxide or the like, as discussed additionally below. In other cases, the anchors 112 may be formed to include walls, or may be of other suitable configurations for a desired application.

[0036] In some examples, the upper structure 106 includes a layer of sealing material 114, and a spring structure 116, including one or more spring members 118. The upper structure further includes a plate 120, which is rectangular in this example, but which may have any suitable shape in other examples. The spring members 118 in this example may be referred to as beam springs, leaf springs, or other bar-shaped

springs that may have an approximately square or otherwise rectangular cross section, although any other suitable cross section configurations may also be used, as discussed above. Further, the spring members need not be uniform along their lengths, but may taper or the like. In addition, the spring members 118 may for a single cell may differ from each other in shape, length, connection location, and so forth.

[0037] The spring structure 116 may further include spring junctions 122, which generally may overlie the anchors 112. The spring junction 122 may be the portion of at least one spring member 118 that overlies an anchor. In some cases, multiple spring members 118 may intersect at a spring junction 122. The spring structure 116 may further include connector elements 124 that connect the spring members 118 to the plate 120. In some examples, the spring junctions 122 and connector elements 124 may be made from the same contiguous piece of material as the spring members 118 and the plate 120. For instance, etching or other subtractive micromachining techniques may be used to generate the spring structure 116 and the plate 120. Alternatively, additive techniques, such as deposition, may be used, or a combination of additive and subtractive techniques. Additionally, in other examples, the plate 120, the spring members 118, the connector elements 124, and/or the spring junctions 122 may be made from separate materials that are connected to one another, such as using bonding techniques, or the like.

[0038] The spring structure 116 may be defined from the plate 120 by one or more openings 126, which are L-shaped in this example, such that four L-shaped openings 126 located between the spring members 118 and the plate 120 define the shape of the plate 120 and the cross-sectional width of the bar-shaped spring members 118. Accordingly, the stiffness of the spring members 118 may be controlled at least in part based on the size of the adjacent opening 126. For example, by moving or enlarging the openings 126 closer to an outer perimeter 128 of the spring structure 116, the stiffness of the spring members 118 may be decreased and an overall area of the plate 120 may be increased. As mentioned above, the plate 120 may be rigid relative to the spring members 118 so that the displacement profile of the plate is relatively uniform.

[0039] The anchors 112 may support the spring structure 116, and thereby the plate 120 at a known or selected distance from the substrate 108, such that a cavity 130 exists between the sealing member 114 (or the underside of the plate 120 when the sealing member is not present) and the insulation layer 110 (or the upper side of the substrate 108 when the insulation layer is not present). The sealing material 114 may seal the openings 126 between the spring structure 116 and the plate 120 within each cell 102, and may further seal any openings between neighboring cells, as discussed additionally below. In some cases, the sealing material 114 may also serve as an insulation layer so that insulation layer 110 may be optional.

[0040] In addition, as illustrated in FIG. 1, the transducer cell 102 may be included in a transducer array 132 that is made up of a plurality of the transducer cells 102. In some examples, the transducer cells 102 within the array 132 may be grouped into array elements 134, which include subsets of the cells 102 in the array 132. Accordingly, in some cases, one or more array elements 134 may make up the array 132. In the illustrated example, the array 132 includes three of the array elements 134, and each array element 134 includes 3×12 (i.e., 36) cells 102. Of course, implementations herein are not limited to any particular number of cells per array element or

array elements per array. For instance, array elements **134** and the array **132** may be one-dimensional or two-dimensional. A one-dimensional arrangement of cells may include only a single row of cells **102**, whereas, as illustrated in FIG. 1, a two-dimensional arrangement of cells may include cells **102** extending in two directions, e.g., both an x-axis direction and a y-axis direction.

[0041] In some cases, the cells **102** within each array element **134** may operate electrically at least partially independently of cells **102** in the other array elements **134**. In this case, the cells **102** in the same array element **134** may be electrically connected, e.g., in parallel to each other to act as the equivalent of a single capacitor, such as for outputting an electrical signal in reception in response to receiving acoustic energy, and for generating acoustic energy in transmission in response to an inputted electric signal. However, the cells **102** in a first array element **134** may not be directly electrically connected to adjacent cells **102** in an adjacent array element **134**.

[0042] Further, in some examples, the cells **102** in an array element **134** may be sealed (e.g., hermetically sealed) from an external environment. For instance, as discussed additionally below, in some examples, each array element **134** may be sealed independently of the other array elements **134**, which may include a seal around a perimeter **136** of each array element **134**. In addition, the plurality of cells **102** in a particular array element **134** may be sealed together, such that the array element **134** is sealed from the outside environment, but the cells **102** in the same array element **134** are not sealed from each other, and thus a cavity of each cell **102** may be connected to those of the other cells in the same array element **134**. Additionally, or alternatively, in some examples, each cell **102** may be independently sealed from other cells **102** as well as from the exterior environment.

[0043] FIG. 2 illustrates a plan view or topside view of the transducer apparatus of FIG. 1 according to some implementations. In this example, the cell **102** includes the spring structure **116** in a square, rectangular or other shape surrounding the plate **120**. Further, as mentioned above, the size of the L-shaped openings **126** may be adjusted to control the stiffness of the spring members **118**, the size of the connector elements **124**, and the size of the plate **120**.

[0044] FIG. 3A illustrates a side view of the transducer apparatus **100** as taken along line 3A-3A of FIG. 2. From this angle, it may be seen that the cavity **130** forms a transducing gap **302**, which, in this example, is the distance between a top surface **304** of the insulation layer **110**, and a bottom surface **306** of the sealing material **114**. Further, it may be seen that the height of the anchors **112** may be controlled to control, at least in part, the size of the transducing gap **302**. Additionally, in some cases, at least one of the insulation layer **110** or the sealing material **114** may be eliminated. Generally, the transducing gap **302** is the maximum distance that the plate **120** can move toward the substrate **108** before contact is made that stops further movement.

[0045] FIG. 3B illustrates the example transducer apparatus **100** of FIG. 3A in which the plate **120** has been moved toward the substrate **108**, as indicated by arrow **308**. Accordingly, the spring members **118** have flexed or bowed downward, while the plate **120**, which is relatively more rigid than the spring members **118** has remained relatively unbent. Further, the transducing gap **302** has been reduced by the distance that the plate **120** has traveled toward the substrate **108**. Consequently, this movement may cause a change in capacitance

between a first electrode **310** associated with the substrate **108** and a second electrode **312** associated with the plate **120**. For instance, as mentioned above, the first electrode **310** may be the substrate **108** itself, such as in the case that the substrate **108** is a conductive material or at least the portion under the plate **120** has been made conductive. As another example, a conductive layer of metal or other conductor may be deposited on a surface of the substrate, such as an upper surface **314**. Similarly, the plate **120** may be of a conductive material, or at least a portion of the plate **120** over the cavity **130** may be rendered conductive, such as through doping. Thus, in this example, an electrode separation distance **315** is the distance between the respective nearest points of the first electrode **310** and the second electrode **312**, i.e., the distance between the upper surface **314** of the substrate **108** and a lower surface **316** of the plate **120**. As another example, a conductive layer of metal or other conductor may be deposited on a surface of the plate **120**, such as the lower surface **316** or an upper surface **318** of the plate **120**.

[0046] FIG. 4A illustrates a side cross-sectional view of the spring structure **116** and the plate **120** as taken along line 4A-4A of FIG. 2. In this example, the spring members **118** have a rectangular cross section (in this disclosure the term rectangular includes square unless specifically stated otherwise). However, other suitable cross sections may be used for the spring members **118**, as enumerated above.

[0047] FIG. 4B illustrates the spring structure **116** and plate **120** of FIG. 4A in which the plate **120** has been moved toward the substrate **108** (not shown in FIG. 4B), as indicated by arrow **402**. Accordingly, the spring members **118** have flexed, bowed, or otherwise bent downward and inward, while the plate **120**, which is relatively more rigid than the spring members **118**, has remained relatively unbent. For instance, a primary displacement of the plate **120** may be due to bending downward of the spring members **118** along the longitudinal axes of the spring members (i.e., downward in a z-axis direction of arrow **308**, as discussed above with respect to FIG. 3B, and the direction of arrow **402** in FIG. 4B). Further, the spring members **118** may have also twisted slightly about a longitudinal axis. Accordingly, the spring members **118** may exert a biasing force to return the plate **120** to its original position. In this example, the biasing force has at least three components, i.e., a y-axis component **404**, an x-axis component **406** and a torsional component **408**.

[0048] FIG. 5 illustrates the example transducer apparatus **100** including a plurality of the example transducer cells **102** arranged in a side-by-side configuration, such as may be included in a transducer element or other portion of an array **502** according to some implementations. The vertical and horizontal dashed lines define the boundaries of individual cells **102**. For instance, a plurality of the transducer cells **102** may be fabricated side-by-side, i.e., adjacent to one another to produce at least a portion of the array **502** of the transducer cells **102**. Accordingly, a plurality of the plates **120** may be fabricated adjacent to one another from a single substrate, as discussed above, with the L shaped openings **126** defining each plate **120**. Furthermore, adjacent springs **118** may be separated from each other by an elongate opening **504**. In this example, the spring junctions **122** may form the junction of as many as eight separate spring members **118**, from as many as four separate cells **102**. As discussed above, each spring junction **122** may overlie an anchor extending from a substrate (not shown in FIG. 5). In some examples, the cells **102** may be individually addressable such that, in the case of transmis-

sion, an electric signal provided to each cell 102 may be individually controlled or, in the case of reception, a signal received from each cell 102 may be individually detected. In other examples, the individual cells 102 are not individually addressable, and instead electric signals may be sent to and received from multiple cells 102 in unison.

[0049] FIG. 6 illustrates the example transducer apparatus 100 including a plurality of example transducer cells 102 arranged in an array 602 according to some implementations. In this example, rather than having the elongate openings 504 separating each cell 102, as discussed above with respect to FIG. 5, adjacent cells 102 may share spring members 118. For example, the plurality of plates 120 may be fabricated adjacent to one another with the L shaped openings 126 defining each plate 120. However, in this example, since neighboring cells share spring members 118, spring junctions 122 form the junction of only up to four springs 118, rather than eight as in the previous example of FIG. 5.

[0050] FIG. 7 illustrates an example of the transducer apparatus 100 formed into an array element 702 of six individual cells 102 according to some implementations. For example, the array of FIG. 7 may correspond to the portion of the array of FIG. 5 discussed above. Alternatively, the portion of the array of FIG. 6 may be similarly configured as an array element 702. In either event, the array element 702 may include a perimeter seal 704 around a perimeter 706 of the array element 702. In both FIG. 5 and FIG. 6, the cavities of the cells 102 are in communication with each and are therefore interconnected and not sealed individually. Accordingly, multiple cells 102 can be sealed together as illustrated in the example of array element 702 of FIG. 7. For example, the perimeter seal 704 may be disposed around the outer perimeter of the array element 702. Consequently, the sealing material 114 may seal the upper side of the cavities, the substrate 108 (not shown in FIG. 7 may seal the underside of the cavities, and the perimeter seal 704 may seal the outer perimeter 706 of the array element 702. Following fabrication of the array element 702, a vacuum may be applied to the cavities and the sealing of the cavities may be completed to provide the transducer array element 702 with vacuum-sealed cavities.

[0051] FIG. 8 illustrates an example of the transducer apparatus 100 formed into at least a portion of an array 802 of multiple cells 102, which may be similar to the portion of the array 502 discussed above with respect to FIG. 5. In this example, each of the multiple cells 102 may have individually sealed cavities. Further, in FIG. 8, for clarity purposes, the elongate openings 504 are shown slightly larger and the sealing material 114 is not shown, to better illustrate a plurality of sealing walls 804 that may extend upward from the substrate in a manner similar to the anchors 112 in some examples. For instance, the sealing walls 804 may be contiguous with the anchors 112, and of the same height, so as to contact the sealing material 114 when the sealing material 114 is applied to the anchors 112. Accordingly, the sealing wall 804 and spring anchors 112 may define individual cavities 130 for each cell 102 to enable sealing of the individual cavities 130 of each cell 102.

[0052] FIG. 9 illustrates an example transducer apparatus 900 according to some implementations that may operate similarly to the various implementations of the transducer apparatus 100 discussed above. For example, rather than having cells of a substantially square shape, as discussed above with respect to FIGS. 1-8, the cells can be fabricated to have

various other suitable shapes, such as an elongate rectangle, a circle, a triangle, a ring, a hexagon, and so forth. In the example of FIG. 9, the transducer apparatus 900 includes a plurality of cells 902 in which each cell 902 includes an elongate rectangular plate 904 that extends past multiple spring junctions 122. Accordingly, a plurality of elongate openings 906 may be formed between adjacent plates 904 to define the plates 904 and to define the spring members 118, which are shared by adjacent cells 902. The transducer apparatus 900 of FIG. 9 may be operated in a manner similar to that discussed above with respect to the transducer apparatus 100.

[0053] FIGS. 10A and 10B illustrate a perspective view and a plan view, respectively, of an example cell 102 of the transducer apparatus 100 including a plate enhancement structure according to some implementations. For instance, to improve the plate rigidity while reducing the mass of the plate 120, an enhancement structure 1002 can be disposed on the plate 120. The enhancement structure 1002 may include a plurality of beams, ridges, corrugations, struts, or other structures, that can act as stiffening elements, which can improve the displacement uniformity of the plate 120, and prevent bending of portions of the plate 120 relative to other portions. In the illustrated example of FIGS. 10A and 10B, the enhancement structure 1002 includes multiple cross beams 1004 that are formed on the upper surface of the plate 120. The enhancement structure 1002 may be included with the plate 120 so that the ratio of the resonant frequency of the plate 120 over the mass of the plate 120 is improved, as compared to a plate of similar mass without the enhancement structure 1002. In the illustrated example, the cross beams 1004 may be constructed from the same material as the plate 120, e.g., by etching, or from a different material that is deposited, bonded or otherwise attached to the upper surface of the plate 120.

[0054] FIGS. 11A and 11B illustrate plan views of a transducer apparatus 1100 including an example cell 1102 according to some implementations. In this example, a plurality of spring members 1104 are cantilevered from respective spring junctions 1106 and are connected to a central portion 1108 of a plate 1110. Furthermore, a plurality of openings 1112 may be formed in the plate 1110 to define the spring members 1104 and to separate the plate 1110 of this cell 1102 from adjacent cells 1102 when the cells 1102 are formed into at least a portion of an array as discussed above. The spring junctions 1106 may be disposed over anchors (not shown in FIG. 11A) as discussed above, so that the plate 1110 is suspended over a cavity for resilient movement similar to the plate 120 in the examples discussed above. Consequently, the transducer apparatus 1100 may operate in a manner similar to the transducer apparatus 100 discussed above.

[0055] FIG. 11B illustrates a plan view of the transducer apparatus 1100 including an enhancement structure 1114 similar to the enhancement structure 1002 discussed above with respect to FIGS. 10A and 10B in this example, the enhancement structure 1114 includes a pair of crossed beams 1116. As mentioned above, the enhancement structure 1114 may increase the stiffness of the plate 1110 substantially without substantially increasing the mass of the plate 1110.

[0056] FIG. 12 illustrates a plan view of a transducer apparatus 1200 including a cell 1202 according to some implementations. In the example of FIG. 12, one of the spring members 118 has been eliminated from each side of the plate 120. For example, four enlarged openings 1206 may be formed to define the plate 120 and the four spring members 118. Accordingly, a spring structure 1206 of this example

includes one spring member **118** attached to each side of the plate **120**, and cantilevered from its respective spring junction **122**. The transducer apparatus **1200** may operate in a manner similar to the transducer apparatus **100** discussed above.

[0057] FIGS. **13A** and **13B** illustrate a cross-sectional view of an example anchor of a transducer apparatus according to some implementations. In this example, the upper structure **106** of the transducer apparatus **100** may be secured to the lower structure **104** of the transducer apparatus through the anchor **112**. For instance, an opening **1302** may be formed through the spring junction **122**, the sealing material **114** and into the anchor **112** as illustrated in FIG. **13A**. The opening **1302** may be a generally conical opening, a cylindrical opening, a rectangular opening, or any other suitable shape.

[0058] As illustrated in FIG. **13B**, a plug material **1304** may be deposited into the opening **1302** to secure the upper structure **106** relative to the lower structure **104** to further ensure the reliability of the anchor **112**. The plug material **1304** may strengthen the adhesion between the upper structure **106** and the anchor **112**. In some examples, the plug material **1304** may be a dielectric material or nonconductive material. The plug material **1304** may be deposited, sputter-coated, spin-coated, thermally grown, etc., over the opening **1302**, and may be patterned to a desired shape.

[0059] FIGS. **14A-14F** illustrate a side cross-sectional view of an example of the transducer apparatus **100** during select example fabrication operations according to some implementations. The other transducer apparatuses discussed herein may be fabricated similarly.

[0060] As illustrated in FIG. **14A**, a first fabrication substrate **108** may be provided. In some examples, recess patterns optionally may be formed on the upper surface **314** of the substrate **108**. For example, one or more first recess pattern **1402** may be formed for receiving one or more respective anchors. In some examples, the recess pattern **1402** may be formed to enable the anchors to include insulation extensions. For instance, in the case that the substrate **108** is conductive and is able to serve at least in part as the first electrode, an insulation extension may reduce parasitic capacitance by extending a non-conductive anchor and/or associated insulation material into the substrate **108**, such as below an area where the transducing gap will be.

[0061] Furthermore, one or more second recess patterns **1404** may be formed in the expected location of respective transducing cells, such as where the bottom of the cavity will be located. This can give the bottom electrode a non-flat electrode surface in some examples. The non-flat surface may be designed to increase the transducer efficiency by increasing average electrical field intensity with given applied voltage. In addition, a third recess pattern **1406** may be formed around a perimeter of the substrate **108**, such as to enable formation of a seal around the perimeter of the substrate **108**, e.g., for sealing a plurality of transducer cells, such as for sealing an array element, as discussed above with respect to FIG. **7**. In addition, in other examples, the recess patterns **1402**, the recess patterns **1404** and/or the recess pattern **1406** are not formed. Thus, in some cases, some or all of the recess patterns **1402**, **1404** and **1406** may be optional and/or other types of recess patterns may be formed.

[0062] The substrate **108** can be any suitable fabrication substrate, such as a silicon wafer, a glass wafer, a quartz wafer or any other substrate suitable for MEMS (microelectromechanical system) fabrication. As mentioned above, in some examples the substrate **108** may be conductive or may be

made conductive, such as through doping of portions of the substrate **108**, so that the substrate may serve as a common first electrode, or portions of the substrate may serve as the first electrode(s). In other examples, one or more layers of conductive material may be patterned onto the substrate, such as at the locations of the recesses **1404**.

[0063] In FIG. **14B**, a first layer **1408** is grown, deposited, bonded to, joined to, or otherwise disposed on the substrate **108**, and patterned to a desired shape to form the anchors **112** that may be used to support the spring structure as discussed above. In some examples, the anchors **112** may be shaped as posts, or the like, extending outward a specified distance from the upper surface **314** of the substrate **108**. The first layer **1408** may further be patterned to form a wall **1410**, which may serve as a seal around the perimeter of a plurality of transducer cells. The material used to form the first layer **1408** may be oxide, nitride, or other suitable dielectric or other non-conductive material. Additionally, in some examples, the anchors **112** may include walls (not shown in FIG. **14B**) formed to define individual cavities corresponding to individual transducer cells, as discussed above, e.g., with respect to FIG. **8**. The walls may seal individually the transducer cells from adjacent cells.

[0064] In FIG. **14C**, an additional layer of insulating material may be grown, deposited, bonded to, joined to, or otherwise disposed on the substrate **108** to be the insulation layer **110**. The material used to form the insulation layer **110** may be oxide, nitride, or other suitable dielectric or other non-conductive material, and may be the same material as the first layer **1408**, or a different material.

[0065] In FIG. **14D**, a second substrate **1412** is joined to or otherwise placed in contact with the anchors **112** and the wall **1410** previously formed on the first substrate **108**. The second substrate **1412** may include the sealing material **114**, a device layer **1414**, an intermediate insulation layer **1416**, and a handling layer **1418**. For example, the second substrate **1412** may be a silicon-on-insulator (SOI) wafer that initially includes the device layer **1414**, the intermediate insulation layer **1416**, and the handling layer **1418**. The sealing material **114** may be grown, deposited, or otherwise disposed on the surface of the device layer **1414** prior to placement of the second substrate **1412** on the first substrate **108**. The sealing material **114** may be oxide, nitride, polyimide, parylene, or any other suitable flexible material. Following disposing of the sealing material **114** on the device layer **1414**, the second substrate **1412** is flipped and bonded with the substrate **108**, which forms cavities **130** between the first substrate **108** and the second substrate **1412**. Any suitable bonding techniques may be used for bonding the sealing material **114** to the upper surfaces of the anchors **112** and/or the sealing wall **1410**. As described below, at least a portion of the plate **120** and/or the spring structure **116** can be fabricated from the device layer **1414**. Further, in some examples, the sealing material **114** is not included, or the sealing material may be deposited at a later stage and/or in a different location, such as overlying the plate and spring structure. Additionally, in some examples, the anchors **112** may be formed or otherwise disposed on the second substrate **1412** before disposing the second substrate onto the first substrate **108**.

[0066] In FIG. **14E**, the handling layer **1418** and the intermediate insulation layer **1416** are removed, leaving the device layer **1414** exposed. In some examples, an opening **1420** is formed through the device layer **1414**, the sealing material **114**, and the sealing wall **1410**, to enable electrical access to

the first substrate **108** near the perimeter. Additionally, a desired pattern **1422** can be formed on the device layer **1414** to control the mechanical properties of the portions of the device layer **1414** that will become the plate(s) **120**. For example, as discussed above, the upper surface of the plate may be machined to include one or more enhancement structures, such as stiffening elements (e.g., beams, struts, corrugations, etc.) as discussed above with respect to FIGS. **10A**, **10B** and **11B**. For example, the pattern **1422** can also be formed in the spring member area to make the spring membrane thinner, and thereby more flexible.

[0067] In FIG. **14F**, in some examples, a conductive layer **1424** of metal or other conductive material may be deposited and patterned onto the device layer **1414** to serve as the top or second electrode. Alternatively, in some examples, the device layer **1414** may be conductive, or select portions of the device layer **1414** may be made conductive to serve as the second electrode. Additionally, the device layer **1414** and the metal layer **1424** may be etched or otherwise micromachined to form trenches or other openings **1426** for forming the plate **120**, the spring members **118**, and the spring junctions **122**. For example, the device layer **1414** may be etched down to the sealing material **114**. If the device layer **1414** is conductive, the device layer **1414** can also be etched to form electrical isolation between particular cells **102** of the transducer apparatus **100**, such as between cells that are grouped into different array elements. Thus, individual array elements of a CMUT array may be independently electrically addressable by having independently addressable second electrode portions with a common first electrode portion. For instance, as mentioned above, the first substrate **108** can be the first electrode portion if made of a conductive material, such as silicon. Alternatively, a conductive layer may be formed on the first substrate **108** as the first electrode portion if the substrate **108** is not sufficiently conductive.

[0068] FIGS. **15A-15F** illustrate a side cross-sectional view of an example of the transducer apparatus **100** during select fabrication operations according to some implementations. The fabrication techniques of FIGS. **15A-15F** may include the fabrication of individually sealed cells, whereas in the fabrication techniques of FIGS. **14A-14F**, the cells might not be individually sealed from each other. The other transducer apparatuses discussed herein may be fabricated similarly.

[0069] In FIG. **15A**, a first fabrication substrate **108** of the transducer apparatus **100** may be a silicon wafer, a SOI wafer, a quartz wafer, a glass wafer, or any other material suitable for MEMS processing, as discussed above. If a non-conductive substrate is used, then a conductive material **1502** may be patterned or otherwise disposed on the substrate as the first electrodes. For instance, a layer of the conductive material **1502** may be deposited at particular locations on the substrate **108** corresponding to where the cells **102** will be formed.

[0070] In FIG. **15B**, a layer of sacrificial material **1504** may be formed, deposited, or otherwise disposed on the first substrate **108** and patterned according to discrete locations of the conductive material **1502** and/or the locations at which the cells **102** will be located. Openings **1506** may be left between the portions of the sacrificial material **1504** for formation of the anchors, as discussed below. Examples of suitable sacrificial materials include oxide, polysilicon, metal, polymer, photoresist, and so forth.

[0071] In FIG. **15C**, a layer of the sealing material **114** may be formed, deposited, or otherwise disposed over the sacrifi-

cial material **1504**. For example, the sealing material **114** may be patterned to be a desired shape, may overlie the portions of sacrificial material **1504**, and may at least partially fill the openings **1506** between the portions of the sacrificial material **1504** at the intended cell locations. As mentioned above, examples of suitable sealing material **114** may include oxide, nitride, metal, parylene, polyimide, and other polymers.

[0072] In FIG. **15D**, a layer of silicon or other suitable plate material **1508** is formed on the sealing material **114**. The plate material **1508** may be used to form at least part of the plate and spring structure. An opening **1510** may be formed in the plate material **1508** to enable access to the first electrode(s) corresponding to the conducted material **1502**. In addition, an opening (not shown) may be formed to access the sacrificial material **1504**.

[0073] In FIG. **15E**, the sacrificial material **1504** may be removed to form the cavities **130**. The cavities **130** may be sealed in vacuum so that a vacuum exists in the cavities **130**.

[0074] In FIG. **15F**, in some examples, a conductive layer **1512** of metal or other conductive material may be deposited and patterned onto the plate material **1508** to serve as the top or second electrode. Alternatively, in some examples, the plate material **1508** may be conductive, or select portions of the plate material **1508** may be made conductive to serve as the second electrode. Additionally, the plate material **1508** and the conductive layer **1512** may be etched or otherwise micromachined to form trenches or other openings **1514** for forming the plate **120**, the spring members **118** and spring junctions **122**. For example, the plate material **1508** may be etched down to the sealing material **114**. Further, in this example, the anchors **112** are formed from the plate material. If the plate material **1508** is conductive, the plate material **1508** can also be etched to form electrical isolation between particular cells **102** of the transducer apparatus **100**, such as between cells that are included in separate array elements. Thus, individual array elements of a CMUT array may be independently electrically addressable by having independently addressable second electrodes with a common bottom electrode or with individually addressable bottom electrodes. Optionally, the sealing material **114** can also be deposited after the plates and springs are formed.

[0075] FIG. **16** illustrates an example process for fabricating a transducer apparatus according to some implementations. This process is illustrated as a collection of blocks in a logical flow diagram, which represents a sequence of operations. The order in which the operations are described should not be construed as a limitation. Any number of the described blocks can be combined in any order and/or in parallel to implement the process, or alternative processes, and not all of the blocks need be executed, as some of the operations may be optional.

[0076] At **1602**, the process may include disposing a plurality of anchors on a first substrate. For example, disposing the plurality of anchors on the first substrate may be by any suitable technique. Accordingly, the anchors may be grown, deposited, etched, formed, bonded to, joined to, or otherwise disposed on the first substrate.

[0077] At **1604**, the process may include joining a second substrate on the plurality of anchors. Furthermore, one of the first substrate or the second substrate may include a sealing material already deposited thereon and a device layer. Alternatively, in other examples, the sealing material may be applied during a subsequent operation.

[0078] At **1606**, the process may include forming, in the device layer, a plate and a spring structure such that the plurality of anchors support the spring structure and the spring structure supports the plate. In some examples, the spring structure may include a plurality of bar-shaped spring members, which may be cantilevered from a single anchor, or which may be supported between multiple anchors. Further, in some cases, a plurality of the plates may be formed side-by-side to form a first plurality of transducer cells as a first array element and a second plurality of transducer cells as a second array element. Thus, multiple array elements may be formed to create, at least in part, a transducer array. Furthermore, a first perimeter of the first array element may be sealed, and a second perimeter of the second array element may be separately sealed so that the first array element is sealed separately from the second array element. For instance, the cavities of the transducer cells in the first array element may be connected to each other, but sealed from the environment external to the first array element. Similarly, the cavities of the transducer cells in the second array element may be connected to each other, but sealed from the environment external to the second array element. Further, in other examples, each cavity of each cell may be individually sealed.

[0079] At **1608**, the process may optionally include forming or otherwise disposing an enhancement structure on or in the plate. For example, the enhancement structure may be one or more stiffening elements such as cross beams, corrugations, structure the like that may add stiffness to the plate. The enhancement structure may be disposed on the plate before or after the processing steps of block **1606** discussed above, and the disposing may include any suitable technique, including growing, depositing, etching, forming, bonding, joining, or the like.

[0080] At **1610**, the process may optionally include forming an opening in at least one spring junction and an underlying anchor. For example, a conical, cylindrical or other shape opening may be formed through the spring junction into the anchor.

[0081] At **1612**, the process may optionally include placing a plug material into the opening to secure the spring junction to the underlying anchor. For example, the plug material may be any suitable material, such as an oxide, and may securely bond the spring junction to the underlying anchor.

[0082] FIG. **17** illustrates an example process **1700** for fabricating a transducer apparatus according to some implementations. This process is illustrated as a collection of blocks in a logical flow diagram, which represents a sequence of operations. The order in which the operations are described should not be construed as a limitation. Any number of the described blocks can be combined in any order and/or in parallel to implement the process, or alternative processes, and not all of the blocks need be executed, as some of the operations may be optional. In some cases, the process **1700** may be used to form transducer cells that are individually sealed.

[0083] At **1702**, the process may include disposing a sacrificial material on a first substrate. For example, the sacrificial material may be disposed on the substrate at locations at which the transducer cells will be formed.

[0084] At **1704**, the process may include disposing a sealing material over the sacrificial material. For example, the sealing material may be a layer of flexible material that overlies the sacrificial material and spaces in between the sacrificial material.

[0085] At **1706**, the process may include disposing a plate material over the sealing material. In some examples, the plate material may be deposited or otherwise formed over the flexible material.

[0086] At **1708**, the process may include removing the sacrificial material and sealing the resulting cavity left by the removal of the sacrificial material. For example, the cavity may be sealed in a vacuum, which results in a vacuum in the cavity. Accordingly, a plurality of sealed cavities may be made which may correspond to a plurality of transducer cells.

[0087] At **1710**, the process may include forming a plate, a spring structure, and anchors from the plate material. For example, etching or other micro-machining techniques may be used to form the plate, a spring structure supporting the plate and anchors supporting the spring structure.

[0088] Additionally, the processes described herein are only several examples of possible processes provided for discussion purposes. Numerous other variations will be apparent to those of skill in the art in light of the disclosure herein. Further, while the disclosure herein sets forth several examples of suitable apparatuses and environments for executing the processes, implementations herein are not limited to the particular examples shown and discussed.

[0089] FIG. **18** illustrates an example transducer apparatus **1800** according to some implementations that may operate similarly to the various implementations of the transducer apparatus **100** discussed above. For example, rather than having cells of a substantially square shape, as discussed above with respect to FIGS. **1-8**, the cells can be fabricated to have various other suitable shapes, such as an elongate rectangle, similar to the example of FIG. **9**. In this example, the transducer apparatus **1800** includes a cell **1802** that comprises an elongate rectangular plate **1804** that extends past multiple spring junctions **122** and connector elements **124** that connect the spring members **118** to the plate **1804**. Accordingly, a plurality of elongate openings **1806** may be formed between the plate **1804** and adjacent plates (not shown in FIG. **18**) to define the plate **1804** and to define the spring members **118**. Further, in this example, the anchors **112** may be wall-shaped anchors that run underneath the spring junctions **122**. In some cases, the anchors **112** may be formed from the same wafer as the plate, and therefore may be contiguous with the material of the plate **1804**. In other examples, the anchors **112** may be formed from the substrate over which the plate **1804** is disposed (not shown in FIG. **18**). Additionally, in other examples, post-type anchors may be used with the configuration of FIG. **18**, rather than wall-type anchors. Further, while the layer of sealing material is not shown in this example, the sealing material may be applied before or after the openings **1806** are fabricated to seal the cavity under the plate **1804**, as discussed above. The transducer apparatus **1800** of FIG. **18** may be operated in a manner similar to that discussed above with respect to the transducer apparatus **100**.

[0090] FIG. **19** illustrates an example transducer apparatus **1900** according to some implementations that may operate similarly to the various implementations of the transducer apparatus **100** discussed above. For example, similar to the example of FIG. **18**, in this example, the transducer apparatus **1900** includes a cell **1902** that comprises an elongate rectangular plate **1904** that extends past multiple spring junctions **122** and connector elements **124** that connect the spring members **118** to the plate **1904**. Further, in the example, of FIG. **19**, the cell **1902** includes multiple spring members **118** in series. Accordingly, a plurality of elongate openings **1906** may be

formed in a first row **1908** between the plate **1904** and adjacent plates (not shown in FIG. **19**) to define the plate **1904** and to define a first row **1910** of the spring members **118**. A second row **1912** of elongate opening **1906** may also be formed to define a second row **1914** of spring members **118**. For instance, the configuration of FIG. **19** may allow a larger displacement of the plate **1904** than, for example, the configuration of FIG. **18**.

[0091] Further, in this example, the anchors **112** may be wall-shaped anchors that run underneath the spring junctions **122**. In some cases, the anchors **112** may be formed from the same wafer as the plate, and therefore may be contiguous with the material of the plate **1904**. In other examples, the anchors **112** may be formed from the substrate over which the plate **1904** is disposed (not shown in FIG. **18**). Additionally, in other examples, post-type anchors may be used with the configuration of FIG. **19**, rather than wall-type anchors. Further, while the layer of sealing material is not shown in this example, the sealing material may be applied before or after the openings **1906** are fabricated to seal the cavity under the plate **1804**, as discussed above. The transducer apparatus **1900** of FIG. **19** may be operated in a manner similar to that discussed above with respect to the transducer apparatus **100**.

[0092] Although the subject matter has been described in language specific to structural features and/or methodological acts, the subject matter defined in the appended claims is not limited to the specific features or acts described above. Rather, the specific features and acts described above are disclosed as example forms of implementing the claims.

What is claimed is:

1. A transducer apparatus comprising:
 - a substrate including a first electrode portion;
 - a plate including a second electrode portion;
 - at least one spring member connected to the plate;
 - at least one anchor between the substrate and the at least one spring member to support the spring member away from the substrate, wherein:
 - the at least one spring member is bar-shaped; and
 - the at least one spring member supports the plate, at least in part, to allow relative movement between the plate and the substrate.
2. The transducer apparatus as recited in claim 1, wherein:
 - there is a cavity between the plate and the substrate; and
 - the transducer apparatus further comprises a sealing layer to, at least in part, seal the cavity.
3. The transducer apparatus as recited in claim 2, wherein the sealing layer comprises a layer of sealing material disposed on at least one of a top side of the plate or a bottom side of the plate.
4. The transducer apparatus as recited in claim 1, wherein a plurality of the plates are arranged side-by-side to form a plurality of transducer cells, each transducer cell comprising a respective plate, at least one spring member supporting the respective plate, and a cavity between the plate and the substrate.
5. The transducer apparatus as recited in claim 4, wherein:
 - the cavities corresponding to the transducer cells are in communication with each other; and
 - at least a perimeter of the plurality of transducers cells is sealed so as to, at least in part, seal the cavities of the plurality of transducer cells.
6. The transducer apparatus as recited in claim 4, wherein individual cavities corresponding to individual ones of the transducer cells are individually sealed.

7. The transducer apparatus as recited in claim 1, wherein the at least one spring member and the plate are of a same contiguous material and are connected to each other by a connector element of the same contiguous material.

8. The transducer apparatus as recited in claim 1, wherein the at least one anchor comprises a plurality of anchors, the at least one spring member is supported at a first end by a first one of the anchors and supported at a second end by a second one of the anchors.

9. The transducer apparatus as recited in claim 1, wherein:

- a capacitance exists between the first electrode portion and the second electrode portion; and
- changes in a distance between the first electrode portion and the second electrode portion correspond to changes in the capacitance between the first electrode portion and the second electrode portion.

10. The transducer apparatus as recited in claim 1, further comprising:

- a spring junction connected to the spring member and overlying the at least one anchor;
- an opening formed in the spring junction and extending into the at least one anchor; and
- a plug material in the opening to secure the spring junction to the at least one anchor.

11. The transducer apparatus as recited in claim 1, further comprising an enhancement structure disposed on a surface of the plate, the enhancement structure stiffening the plate.

12. A method of fabricating a transducer comprising:

- disposing a plurality of anchors on one of a first substrate and a second substrate;
- joining the first substrate and the second substrate by the plurality of anchors, wherein one of first substrate or the second substrate comprises a sealing material and a device layer; and

forming, in the device layer of the one of the first substrate or the second substrate, a plate and at least one spring member, wherein the at least one spring member is supported by at least one anchor of the plurality of anchors, and the at least one spring member supports the plate to allow relative movement between the plate and the other one of the first substrate or the second substrate.

13. The method as recited in claim 12, wherein:

- forming the plate and the at least one spring member comprises forming at least one opening between the plate and the at least one spring member; and
- the sealing material seals the at least one opening.

14. The method as recited in claim 12, further comprising:

- forming a plurality of the plates side-by-side to form a plurality of transducer cells, each transducer cell comprising a respective plate; and

sealing at least a perimeter of the plurality of transducer cells.

15. The method as recited in claim 12, further comprising:

- forming a plurality of the plates side-by-side to form a first plurality of the transducer cells as a first array element and a second plurality of the transducer cells as a second array element; and

sealing a first perimeter of the first array element, and sealing a second perimeter of the second array element.

16. A transducer apparatus comprising:

- a substrate including a first electrode portion;
- a plate including a second electrode portion;
- a plurality of spring members connected to the plate;

a plurality of anchors between the substrate and the spring members to support the spring members away from the substrate; and

a cavity located between the plate and the substrate, wherein the spring members allow the plate including the second electrode portion to move toward and away from the substrate including the first electrode portion such that changes in a distance between the first electrode portion and the second electrode portion correspond to changes in a capacitance existing between the first electrode portion and the second electrode portion.

17. The transducer apparatus as recited in claim **16**, wherein at least one of the spring members is bar-shaped and supported at a first end by one of the anchors and connected at a second end to the plate.

18. The transducer apparatus as recited in claim **16**, wherein at least one of the spring members is bar shaped and supported at a first end by a first one of the anchors, supported at a second end by a second one of the anchors, and connected to the plate by a connector element.

19. The transducer apparatus as recited in claim **16**, wherein the plurality of spring members and the plate are of a same contiguous material and are connected to each other by a connector element of the same contiguous material.

20. The transducer apparatus as recited in claim **16**, further comprising a sealing layer to, at least in part, seal the cavity,

wherein the sealing layer comprises a layer of sealing material disposed on at least one of a top side of the plate or a bottom side of the plate.

21. A method of fabricating a transducer comprising:
disposing a sacrificial material on a substrate;
disposing a sealing material over the sacrificial material;
disposing a plate material over the sealing material;
removing the sacrificial material to obtain a cavity between the substrate and the plate material; and
forming, in the plate material, a plate and at least one spring member connected to the plate, wherein at least one anchor supports the at least one spring member away from the substrate, and the at least one spring member enables movement of the plate toward and away from the substrate.

22. The method as recited in claim **21**, further comprising forming the at least one anchor from the plate material or the sealing material.

23. The method as recited in claim **21**, further comprising following removal of the sacrificial material, sealing the cavity in a vacuum.

24. The method as recited in claim **21**, further comprising forming a plurality of the plates, spring members, and cavities to form a plurality of transducing cells, wherein individual cavities corresponding to respective transducing cells are sealed from other cavities of adjacent transducing cells.

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